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DOE HANDBOOK

RADIOLOGICAL SAFETY TRAINING FOR ACCELERATOR FACILITIES

U.S. Department of Energy
Washington, D.C. 20585

FSC 6910

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Foreword

This Handbook describes a recommended implementation process for core training as outlined in the *DOE Radiological Control Manual (RCM)*. Its purpose is to assist those individuals, both Department of Energy (DOE) employees and Managing and Operating (M&O) contractors, identified as having responsibility for implementing the core training recommended by the *RCM*. This training may also be given to workers in accelerator facilities to assist in meeting their job-specific training requirements of 10 CFR 835.

The Handbook contains recommended training materials consistent with other DOE standardized core radiological training material. These training materials consist of the following documents:

> **Program Management Guide** - This document contains detailed information on how to use the Handbook material.
>
> **Instructor's Guide** - This document contains a lesson plan for instructor use, including notation of key points for inclusion of facility-specific information.
>
> **Student's Guide** - This document contains student handout material and also should be augmented by facility-specific information.

The Handbook was produced in WordPerfect 6.1 and has been formatted for printing on an HP III (or higher) LaserJet printer. Copies of this Handbook may be obtained from the DOE Technical Standards Program Internet site (http://apollo.osti.gov/html/techstds/techstds.html).

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(Part 1 of 3)

Radiological Safety Training for Accelerator Facilities

Program Management Guide

Coordinated and Conducted
for
Office of Environment, Safety & Health
U.S. Department of Energy

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Introduction

Purpose and Scope

This program management guide describes the proper implementation standard for core training as outlined in the *DOE Radiological Control (RadCon) Manual*. It's purpose is to assist those individuals, both Department of Energy (DOE) employees and Managing and Operating (M&O) contractors, identified as having responsibility for implementing the core training recommended by the *RadCon Manual*.

Management Guide Content

The management guide is divided into the following sections:

- Introduction.
- Instructional Materials Development.
- Training Program Standards and Policies.
- Course-Specific Information.

Core Training Goal

The goal of the core training program is to provide a standardized, baseline knowledge for those individuals completing the core training. Standardization of the knowledge provides personnel with the information necessary to perform their assigned duties at a predetermined level of expertise. Implementing a core training program ensures consistent and appropriate training of personnel.

Organizational Relationships and Reporting Structure

The DOE Office of Worker Protection Programs and Hazards Management (EH-52) is responsible for approving and maintaining the standardized core training materials associated with the core training program.

The establishment of a comprehensive and effective contractor site radiological control training program is the responsibility of line management and their subordinates. The training function can be performed by a separate training organization, but the responsibility for quality and effectiveness rests with the line management.

Instructional Materials Development Next

Instructional Materials Development

Target Audience

Course instructional materials were developed for specific employees who are responsible for knowing or using the knowledge or skills for each course. With this in mind, the participant should never ask the question, "Why do I need to learn this?" However, this question is often asked when the participant cannot apply the content of the program. It is the responsibility of management to select and send workers to training who need the content of the program. When workers can benefit from the course, they can be motivated to learn the content and apply it on their jobs. Care should be taken to read the course descriptions along with the information about who should attend. Participants and DOE facilities alike will not benefit from workers attending training programs unsuitable for their needs.

Prerequisites

A background and foundation of knowledge facilitates the trainee in learning new knowledge or skills. It is much easier to learn new material if it can be connected or associated to what was previously learned or experienced. Curriculum developers who have been involved in preparing instructional materials for the core training know this and have established what is referred to as "prerequisites" for each course.

Certain competencies or experiences of participants were also identified as necessary prior to participants attending a course. Without these competencies or experiences, participants would be at a great disadvantage and could be easily discouraged and possibly fail the course. It is not fair to the other participants, the unprepared participant, and the instructor to have this misunderstanding.

Workers who do not possess the necessary prerequisites should not register for a course.

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Instructional Materials Development (continued)

Training Materials

Training materials for the core program consist of lesson plans, study guides, training aids, handouts, and in some cases, video. The core training content should be presented in its entirety. Overhead transparencies are sometimes provided in support of the core training content and may be supplemented with updated or facility-specific information.

Supplemental material and training aids may be developed to address facility-specific radiological concerns and to suit individual training styles. References are cited in each lesson plan and may be used as a resource in preparing facility-specific information and training aids.

Each site is responsible for establishing a method to differentiate the facility-specific information from the standardized core lesson plan material. When additional or facility-specific information is added to the text of the core lesson plan material, a method should be used to differentiate site information from core material.

Training Delivery

Sites are encouraged to expand per provisions in the *RadCon Manual* and enhance the training materials through advanced training technologies. Computer-based training and multimedia are just a sample of such technologies.

Exemptions

Qualified personnel can be exempted from training if they have satisfactorily completed training programs (i.e., facility, college or university, military, or vendor programs) comparable in instructional objectives, content, and performance criteria. Documentation of the applicable and exempted portions of training should be maintained.

Training Program Standards and Policies Next

Training Program Standards and Policies

Qualification of Instructors

The technical instructor plays a key role in the safe and efficient operation of DOE facilities. Workers must be well qualified and have a thorough understanding of the facility's operation, such as processing, handling, and storage of materials, and maintenance of equipment. Workers must know how to correctly perform their duties and why they are doing them. They must know how their actions influence other worker's responsibilities. Because workers' actions are so critical to their own safety and the safety of others, their trainers must be of the highest caliber. The technical instructor must understand thoroughly all aspects of the subjects being taught and the relationship of the subject content to the total facility. Additionally, the instructor must have the skills and knowledge to employ the instructional methods and techniques that will enhance learning and successful job performance. While the required technical and instructional qualifications are listed separately, it is the combination of these two factors that produces a qualified technical instructor.

The qualifications are based on the best industry practices that employ performance-based instruction and quality assurances. These qualifications are not intended to be restrictive, but to help ensure that workers receive the highest-quality training possible. This is only possible when technical instructors possess the technical competence and instructional skills to perform assigned instructional duties in a manner that promotes safe and reliable DOE facility operations.

Technical Qualifications

Instructors must possess technical competence (theoretical and practical knowledge along with work experience) in the subject areas in which they conduct training. The foundation for determining the instructor's technical qualifications is based on two factors:

Continued on Next Page

Training Program Standards and Policies (continued)

Technical Qualifications (continued)

- The trainees being instructed.
- The subject being presented.

The following is an example of a target audience, the subject being taught, and instructor technical qualifications.

TARGET AUDIENCE	SUBJECT BEING TAUGHT	INSTRUCTOR QUALIFICATIONS
Accelerator facilities personnel, visitors, DOE employees	Accelerator hazards and safety training	Demonstrated knowledge and skills in radiation protection, above the level to be achieved by the trainees, as evidenced by previous training/education and through job performance, AND Completion of all qualification requirements for the senior-level radiation protection technician position at the trainees' facility or a similar facility.

Methods for verifying the appropriate level of technical competence may include the review of prior training and education, observation and evaluation of recent related job performance, and oral or written examination. Other factors that may be appropriate for consideration include DOE, NRC, or other government license or certification; vendor or facility certification; and most importantly, job experience. To maintain technical competence, a technical instructor should continue to perform satisfactorily on the job and participate in continuing technical training.

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Training Program Standards and Policies (continued)

Instructional Capability and Qualifications

Qualifications of instructional capability should be based on demonstrated performance of the instructional tasks for the specific course requirements and the instructor's position. Successful completion of instructor training and education programs, as well as an evaluation of on-the-job performance, is necessary for verification of instructional capability. Instructional capability qualification should be granted at the successful completion of an approved professional development program for training instructors. The program should contain theory and practice of instructional skills and techniques, adult learning, planning, conducting, and evaluating classroom, simulator, laboratory, and on-the-job training activities as applicable to the facility or position.

Illustrated talks, demonstrations, discussions, role playing, case studies, coaching, and individual projects and presentations should be used as the principal instructional methods for presenting the instructional training program. Each instructional method should incorporate the applicable performance-based principles and practices. Every effort should be made to apply the content to actual on-the-job experience or to simulate the content in the classroom/laboratory. The appropriate methodology required to present the instructional content will indicate a required level of instructional qualification and skill.

Current instructors' training, education, and job performance should be reviewed to determine their training needs for particular courses. Based on this review, management may provide exemptions based on demonstrated proficiency in performing technical instructor's tasks.

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Training Program Standards and Policies (continued)

Instructional Capability and Qualifications (continued)

Through training or experience, technical instructors should be able to:*

- Review instructional materials and modify to fully meet the needs of the training group.
- Arrange the training facility (classroom/laboratory or other instructional setting) to meet the requirements for the training sessions.
- Effectively communicate, verbally and non-verbally, lessons to enhance learning.
- Invoke student interaction through questions and student activity.
- Respond to students' questions.
- Provide positive feedback to students.
- Use appropriate instructional materials and visual aids to meet the lesson objectives.
- Administer performance and written tests.
- Ensure evaluation materials and class rosters are maintained and forwarded to the appropriate administrative personnel.
- Evaluate training program effectiveness.
- Modify training materials based on evaluation of training program.

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*Stein, F., *Instructor Competencies: the Standards*. International Board of Standards for Training, Performance and Instruction, 1992.

Training Program Standards and Policies (continued)

Selection of Instructors

Selection of instructors should be based on the technical and instructional qualifications specified in the Course-Specific Information section of this guide. In addition to technical and instructional qualifications, oral and written communication skills, and interpersonal skills, should be included in the process of selecting and approving instructors.

Since selection of instructors is an important task, those who share in the responsibility for ensuring program effectiveness should:

- Interview possible instructors to ensure they understand the importance of the roles and responsibilities of technical instructors and are willing to accept and fulfill their responsibilities in a professional manner.

- Maintain records of previous training, education, and work experience.

Procedures for program evaluation will include documentation of providing qualified instructors for generic and facility-specific training programs.

Test Administration

A test bank of questions for each course that has an exam should be developed and content validated. As the test banks are used, statistical validation of the test bank will be performed to fully refine the questions and make the tests as effective as possible. The questions contained in the test bank are linked directly to the objectives for each course. In this way, trainee weaknesses can be readily identified and remedial procedures can be put into place. The test outcomes can also be used to document competence and the acquisition of knowledge.

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Training Program Standards and Policies (continued)

Test Administration (continued)

The test banks should also be used by the instructors to identify possible weaknesses in the instruction. If numerous trainees fail to correctly answer a valid set of questions for an objective, the instruction for that objective needs to be reviewed for deficiencies.

Written examinations may be used to demonstrate satisfactory completion of theoretical classroom instruction. The following are some recommended minimal requirements for the test banks and tests:

- Tests are randomly generated from the test bank.
- Test items represent all objectives in the course.
- All test bank items are content validated by a subject matter expert.
- Test banks are secured and are not released either before or after the test is administered.
- Trainees should receive feedback on their test performance by showing percentages of correct and incorrect responses by objective.
- Trainees should be provided with the correct answers to incorrect responses.
- For the first administrations of tests, a minimum of 80% should be required for a passing score.

Test administration is critical in accurately assessing the trainee's acquisition of knowledge being tested.

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Training Program Standards and Policies (continued)

Test Administration (continued)

The following rules should be adhered to:

- Tests should be announced at the beginning of the training sessions.
- Instructors should continuously monitor trainees during completion of tests.
- All tests and answers should be collected at the conclusion of each test.
- No notes can be made by trainees concerning the test items.
- Every effort should be made to eliminate all noise during the test.
- No talking (aside from questions) should be allowed.
- Answers to questions during a test should be provided, but answers to test items should not be provided or alluded to.
- Where possible, multiple versions of each test should be produced from the test bank for each test administration.
- After test completion, trainees should turn in their materials and leave the room while other trainees complete their tests.
- Trainees should receive the results of their test within one week of test completion.
- Trainee scores on the tests should be held as confidential.

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Training Program Standards and Policies (continued)

Program Records and Administration	Training records and documentation shall meet the requirements of 10 CFR 835.704.
Training Program Development/Change Requests	All requests for program changes and revisions should be sent to DOE EH-52 using the "Request for Changes to Standardized Core Training Materials" form provided with each program management guide.
Audit (internal and external)	Internal verification of training effectiveness should be accomplished through senior instructor or supervisor observation of practical applications and discussions of course material. All results should be documented and maintained by the organization responsible for Radiological Control training. The core training program materials and processes should be evaluated on a periodic basis by DOE-HQ. The evaluation should include a comparison of program elements with applicable industry standards and requirements.
Evaluating Training Program Effectiveness	Verification of the effectiveness of Radiological Control training should be accomplished per DOE/EH-0258T-1, "General Employee Radiological Training and Radiological Worker Training, Program Management Guide." In addition, DOE/EH has issued guidelines for evaluating the effectiveness of radiological training through the DOE Operations Offices and DOE Field Offices. For additional guidance, refer to DOE STD 1070-94, "Guide for Evaluation of Nuclear Facility Training Programs."

Course-Specific Information Next

Course-Specific Information

Purpose	This section of the program management guide is to assist those individuals assigned responsibility for implementing the *Radiological SafetyTraining for Accelerator Facilities.* Standardized implementation of this training ensures consistent and appropriate training for all personnel.
Course Goal	Upon completion of this training, the student will have a basic understanding of the characteristics of accelerators and the precautions and safeguards needed for working in an accelerator facility.
Target Audience	Individuals who have been assigned radiological duties in accelerator facilities.
Course Description	This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the characteristics of accelerators and the precautions needed for working in a DOE accelerator facility. This course is developed in accordance with Article 664 of the *RadCon Manual*.
Prerequisites	Rad Worker I or Rad Worker II
Length	2 - 4 hours (depending on facility-specific information).
Test Bank	On a site-by-site basis.
Retraining	Facilities should determine the appropriate retraining interval.
Instructor Qualifications	Instructors of this course have a major role in making it successful and meeting the specified objectives. Instructors must have related experience and be technically competent. In this course it is imperative that the instructor have the background and experience of

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Course-Specific Information (continued)

Instructor Qualifications (continued)

working in an accelerator facility. Instructors must be able to relate their own work experience to the workers in an accelerator facility. Instructors must be able to answer specific questions and use a variety of instructional material to meet the objectives.

Education:

Minimum of B.S. degree in Health Physics or related discipline is preferred.

Certification:

Certification by American Board of Health Physics (ABHP) or National Registry of Radiation Protection Technologists (NRRPT) is preferred.

Experience:

At least five years of applied radiological protection experience in an operating radiological facility is preferred. Experience in radiological protection at the applicable accelerator facility, such as completion of all qualification requirements for the senior-level radiation protection technician position at the trainees' facility or a similar facility is preferred. The areas of experience should include:

- Radiological controls associated with accelerators.
- Conducting surveys and monitoring at accelerator facilities.

Intimate knowledge of Federal regulations and guidance, and best nuclear industry practices, pertaining to radiological protection. Through training or experience, technical instructors should be able to effectively communicate, verbally and non-verbally, lessons to enhance learning.

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Course-Specific Information (continued)

Materials Checklist

The following checklist should be used to ensure all training materials are available. All materials are provided in WordPerfect 6.1® format.

- Program Management Guide.
- Instructor's Guide.
- Student's Guide.

The following checklist should be used before training is provided to ensure equipment is available and working.

- Overhead projector.
- Screen.
- Flip chart.
- Markers.

Bibliography Next

Bibliography: **<u>DOE standards, handbooks, and technical standards lists (TSLs)</u>. The following DOE standards, handbooks, and TSLs form a part of this document to the extent specified herein.**

U.S. Department of Energy, *Guidelines for Evaluation of Nuclear Facility Training Programs*, DOE -STD 1070-94.

U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-NE-STD-1001-91, Washington, D.C. (1991).

U.S. Department of Energy, *Radiological Control Manual*, DOE/EH-0256T, Washington, D.C. (1994).

U.S. Department of Energy, McCall, R.C. et. al, *Health Physics Manual of Good Practices for Accelerator Facilities*, SLAC-327, Stanford Linear Accelerator Center, Stanford, CA, April 1988.

U.S. Department of Energy, *Safety of Accelerator Facilities*, DOE Order 5480.25.

U.S. Department of Energy, *Personnel Selection, Qualification, Training and Staffing Requirements at DOE Reactors and Non-Reactor Nuclear Facilities,* DOE Order 5480.20A.

<u>Other government documents, drawings, and publications</u>. The following government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise indicated, the issues of these documents are those cited in the contracting document.

Title 10, Code of Federal Regulations, Part 835, *Occupational Radiation Protection*.

<u>Non-Government documents</u>

Cooper, L., *An Introduction to the Meaning and Structure of Physics,* Harper & Row, Publishers, NY, 1968.

Bibliography (continued)

Kernan, W. J., Accelerators, U.S. Atomic Energy Commission, Division of Technical Information, *Understanding the Atom Series*.

Metropolis, K., editor, *The Superconducting Super Collider, An Introduction to Radiation Protection for the Superconducting Super Collider*, Task Force Report SSC-SR-1027, November 10, 1987.

Patterson, W. H., Thomas R. H., editors, *A History of Accelerator Radiation Protection, Personal and Professional Memoirs*, Nuclear Technology Publishing, Kent, England, 1994.

Toohig, T.E., editor, Workshop on Radiological Aspects of SSC Operations, SSC-SR-1031, May 1987.

Universities Research Association, *To the Heart of Matter - The Superconducting Super Collider*, Universities Research Association, Washington D.C., January 1987.

REQUEST FOR CHANGES TO STANDARDIZED CORE TRAINING MATERIALS

Send forms to: U.S. Department of Energy
Office of Worker Health and Safety (EH-52)
Germantown, MD 20874 or fax to: (301) 903-7773
Attn: Peter O'Connell

Date of Request: __________ Program: ________ GERT ________ RW ________ RCT ________ Other	Lesson No. _______ Page No. _______ Article No. _______ ________ SG ________ LP ________ EB ________ TA	________________________________ Facility Requesting Change ________________________________ Contact Person ________________________________ Telephone Number - Fax Number

Description of change request:

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Suggested alternative:

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For Official Use Only:

☐ Accepted
☐ Accepted as modified, see attachment
☐ Not accepted, see attachment

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Signature Date

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Radiological Training for Accelerator Facilities

Instructor's Guide

Coordinated and Conducted
for
Office of Environment, Safety & Health
U.S. Department of Energy

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STANDARDIZED CORE COURSE MATERIALS

Course Goal:	Upon completion of this training, the student will have a basic understanding of the characteristics of accelerators and the precautions and safeguards needed for radiological safety while working in an accelerator facility.
Target Audience:	Individuals who have been assigned radiological duties in accelerator facilities.
Description:	This course illustrates and reinforces the skills and knowledge needed to provide personnel with an understanding of the characteristics of accelerators and the radiological safety precautions needed for working at an accelerator facility. Note: This lesson is not intended to be a requirement of all accelerator facilities but rather a resource to be used at the discretion of the facility training organization. Accelerator facilities may use any portion of this guide. Note: Facility-specific information that requires each facility to input information is denoted as "Facility-Specific."
Prerequisites:	Training that is considered commensurate with facility-specific hazards. Note: This training material is designed to augment the DOE Rad Worker core training. This course includes Rad Worker Training material as applicable to accelerator facilities.
Length:	2-4 hours (depending on facility-specific information).

Terminal Objective and Enabling Objectives Next

Terminal Objectives: At the end of this course, the participant should be able to demonstrate a basic understanding of the characteristics of accelerators and the radiological precautions for working at an accelerator facility.

Enabling Objectives:

EO-01 IDENTIFY uses for accelerators.

EO-02 STATE the type(s) of accelerators at the facility.

EO-03 STATE type(s) of particles accelerated.

EO-04 DEFINE prompt radiation.

EO-05 DISCUSS the biological effects of radiation characteristic of accelerators.

EO-06 IDENTIFY prompt radiation sources at the facility.

EO-07 DEFINE radioactivation.

EO-08 IDENTIFY activation sources at the facility.

EO-09 IDENTIFY ancillary sources at the facility.

EO-10 IDENTIFY activation products.

EO-11 IDENTIFY engineered and administrative controls at accelerator facilities and personnel protective equipment.

EO-12 DESCRIBE each access mode at the facility and access to beam and beam containment including interlocks and warning devices and systems.

EO-13 DISCUSS site configuration control program.

EO-14 DISCUSS special radiological surveys and techniques.

EO-15 STATE purpose of initial entry survey.

EO-16 DISCUSS special instruments and measurement techniques.

EO-17 STATE site requirements for removing material from beam enclosure.

EO-18 IDENTIFY methods to minimize radioactive waste at the facility. (Facility-Specific)

EO-19 IDENTIFY facility alarms and responses to abnormal conditions. (Facility-Specific)

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Training Aids Next

Training Aids:	Overhead transparencies (may be supplemented or substituted with updated or Facility-Specific information).
Equipment Needs:	o Overhead projector. o Screen. o Flip chart. o Markers.
Student Materials:	Student's Guide

Bibliography Next

BIBLIOGRAPHY

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U.S. Department of Energy, *Radiological Control Manual*, DOE/EH-0256T, Washington, D.C. (1994).

U.S. Department of Energy, McCall, R.C. et. al, *Health Physics Manual of Good Practices for Accelerator Facilities*, SLAC-327, Stanford Linear Accelerator Center, Stanford, CA, April 1988.

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Universities Research Association, *To the Heart of Matter - The Superconducting Super Collider*, Universities Research Association, Washington D.C., January 1987.

Lesson Summary Next

LESSON SUMMARY

Introduction:

Welcome students to the course.

Introduce self to the participants and establish rapport.

Define logistics:

- Safety briefing - exits.
- Restrooms.
- Hours.
- Breaks.
- Sign-in sheets.
- Test - accountability.
- End-of-course evaluation.

Remind the participants that they need to have completed Radiological Work Training prior to this course. They should be familiar with terms like rem, contamination, etc.

Terminal Objective:

At the end of this course, the participant should be able to demonstrate a basic understanding of the characteristics of accelerators and precautions for working at an accelerator facility.

State Enabling Objectives.

Course Content Next

COURSE CONTENT

Briefly review the content of the course, noting that there is a logical sequence ("flow") and that the material covered will be related to the circumstances they can expect to find in the facility workplace and procedures. (You will be inserting and facility-specific accelerator information.)

1. History and Uses of Accelerators.

2. Facility Description.

3 Radiological Concerns.

4. Types of Radiological Controls for Accelerator Facilities .

5. Monitoring at Accelerator Facilities.

6. Radioactive Waste Issues.

7. Abnormal Conditions at Accelerator Facilities.

8. Lessons Learned.

9. Summary and Review.

General

Implementation

This training should be used to supplement the standardized core materials for personnel working at or having access to DOE accelerator facilities. This training is multi-faceted, and different sections can be applied to various target groups.

Lesson Plan and Instructor's Notes Next

Lesson Plan	Instructor's Notes

I. HISTORY AND USES OF ACCELERATORS

A. Definition

Accelerators are devices employing electrostatic or electromagnetic fields to input kinetic energy to molecules, atomic or subatomic particles and capable of creating a radiological area.

Reference 5480.25

B. Need for Accelerators

In the early 1900s, radioactive particles could be obtained only from materials found in nature. The studies that physicists wanted to perform required both higher intensities and higher energies than were obtainable from the natural sources. The ability to vary energy and intensity to suit a particular experiment was also desirable.

In the 1930s, scientists began to build machines that produced the needed degree of control. These machines were called accelerators.

C. The Development of the Accelerator

The earliest accelerators were simple vacuum tubes in which electrons were given an increase in energy by the voltage difference between two oppositely charged electrodes.

Lesson Plan	**Instructor's Notes**

1. Acceleration

   The acceleration of the electron by this electrical force also increases the energy of the electron.

2. Electron volt

   The amount of acceleration is determined by the potential difference measured in volts (V) in this electrical field.

   One electron volt (eV) is the energy gained by an electron accelerated through an electric potential of one volt.

   An electron accelerated across a gap by means of a 10,000 volt, or 10 kilovolt (kV), potential difference is said to have gained 10,000 electron volts (10 keV) of energy after crossing the gap.

D. Van de Graaff Generator

One of the first machines to produce laboratory-accelerated particles was the Van de Graaff generator.

1. Operation

   The Van de Graaff consists of a polished metal sphere and a moveable belt. The function of the belt is to carry an electrical charge up to the sphere where it is stored. This process can be continued until a very high potential is developed in the sphere.

Lesson Plan	Instructor's Notes
2. Early generators In 1929, Van de Graaff built a pilot machine capable of generating 80,000 volts (80 keV). In 1931, a 1.5 million-volt (MeV) machine was built at Princeton.	
3. State of the Art A 25 MeV machine was built and operated at Daresbury Laboratory in the United Kingdom.	
E. Cockcroft-Walton Accelerator In 1932 in England, John D. Cockcroft and Ernest T.S. Walton constructed what is called a linear accelerator using a high-voltage source to accelerate protons through 700,000 volts (700 keV).	
F. Linear Accelerators From the first simple machines (Cockcroft-Walton and Van de Graaff machines) evolved the larger and more elaborate machines. The modern example of this type of accelerator is the linear accelerator, a sophisticated machine used in many scientific and medical applications.	Straight-line accelerators suffer from the disadvantage that the finite length of flight path limits the particle energies that can be achieved.
G. Lawrence and the Development of the Cyclotron The great breakthrough in accelerator technology came in 1930 with Ernest O. Lawrence's invention of the cyclotron.	

Lesson Plan	Instructor's Notes

1. Operation

   In the cyclotron, magnets guide the particle along a spiral path, allowing a single electric field to apply many cycles of acceleration.

2. Prototype

   Soon unprecedented energies were achieved, and the steady improvement of Lawrence's simple machine has led to today's synchrotrons, whose endless circular flight paths allow particles to gain huge energies by passing millions of times through the electric fields that accelerate them.

H. Synchrotrons

A synchrotron accelerates particles using electric fields over and over in a circular path. Magnetic fields are used to bend the particles' trajectories and keep them moving in a circle. The accelerated particles lose energy rounding the curves, so energy must be continuously supplied. The beam is extracted heading toward targets and detectors.

I. Colliders

Until 30 years ago, all accelerators were so-called fixed-target machines in which the speeding particle beam was made to hit a stationary target of some chosen substance.

Lesson Plan	Instructor's Notes
In the early 1960s, physicists had gained enough experience in accelerator technology to be able to build colliders in which two carefully controlled beams are made to collide with each other at a chosen point. The beams for colliders may come from two synchrotrons or two linear accelerators.	
J. Purpose and Uses	EO-01 IDENTIFY uses for accelerators.
Accelerators were originally designed to study (research) the structure of matter. Accelerators today are used not only for basic research purposes, but for many other applications such as:	
○ Production of radioisotopes, such as tritium.	
○ Generation of bremsstrahlung for radiography and radiation therapy.	Define the terms, such as bremsstrahlung and actinide transmutation as necessary.
○ Induction of fusion.	
○ Pumping for lasers.	
○ Detoxification of hazardous waste.	
○ Actinide transmutation.	
○ Production of synchrotron radiation.	
○ Sterilization of food and surgical equipment.	
○ Medical radiation therapy.	

Lesson Plan	Instructor's Notes

II. FACILITY DESCRIPTION

A. Types of Accelerators in Use at Facility (Facility-Specific)

EO-02 STATE the type(s) of accelerators at the site.

Electrostatic accelerators

- Cockcroft-Walton.
- Van de Graaff, Tandem Van de Graaff.

Each facility should discuss the types of accelerators in use at the site.

Linear accelerators (Linac)

- Resonant cavity (standing wave).
- Traveling wave.

Cyclic accelerators

- Synchrotron.
- Cyclotron.
- Betatron.

B. Types of Particles Accelerated at the Facility (Facility-Specific)

EO-03 STATE type(s) of particles accelerated.

C. Facility Layout and Description of Areas/Components (Facility-Specific)

- Injectors.
- Target areas.
- Experimental areas.
- Beamlines.
- Control room.
- Shielding structures.

Each facility should describe and give locations of major components and areas. Discuss radiological hazards associated with the areas/components.

Lesson Plan	Instructor's Notes
III. RADIOLOGICAL CONCERNS A. Prompt Radiation Prompt radiation includes the accelerated particle beam and the radiation produced when the beam interacts with matter or changes direction. It is only present when a beam is operating or being accelerated.	EO-04 DEFINE prompt radiation. EO-05 DISCUSS biological effects of radiation characteristic of accelerators. EO-06 IDENTIFY prompt radiation sources at the facility.
1. Primary beam The primary beam consists of accelerated charged particles prior to any interactions. The primary beam is the most intense form of radiation present at an accelerator facility and is made inaccessible to personnel through engineering design and administrative controls.	Direct exposure to a particle beam can result in a potentially dangerous, or even lethal, dose of radiation.
2. Secondary beam Secondary beam is produced by interaction of the primary beam with targets or beamline components. The secondary beam may consist of: ○ Electromagnetic radiation. ○ Neutrons. ○ Charged particles. ○ Other elementary particles.	

Lesson Plan	Instructor's Notes
3. Skyshine	EO-14 DISCUSS special radiological surveys and techniques. As applicable, discuss the hadron cascade or the radiation field inside the beam caves.
Skyshine is the radiation scattered from air molecules. Accelerator-produced skyshine is usually neutron radiation, scattered after emerging more or less vertically from the shielded enclosure. It can cause elevated radiation fields at ground level considerable distances from the source.	
Due to typical facility design, photon skyshine is usually less of a problem but is a consideration, particularly where radioactive materials are stored.	
4. Electromagnetic radiation	Define the terms.
a. <u>Bremsstrahlung</u>: (photons emitted through the deceleration of charged particles passing through matter).	
b. <u>Electromagnetic cascades</u>: (multiple photons emitted through high-energy interactions).	
c. <u>Synchrotron radiation</u>: (photons emitted as the charged particles are accelerated in a curved path).	

Lesson Plan	Instructor's Notes
5. Neutrons	EO-16 DISCUSS special instruments and measurement techniques.
Neutrons can be produced through nuclear interactions of the primary or secondary beam with matter. They can also be produced by interaction of high-energy photons about with matter (photoneutron reaction). The photoneutron reaction typically requires photons with energy in excess of 10 MeV.	
a. Neutron radiation is a concern within any area where the beam can interact with physical objects.	
b. Location of potential sources of neutron radiation exposure. (Facility-Specific).	Each facility should describe potential sources of neutron radiation exposure.
6. Muons	
Muons are particles that are physically similar to electrons, but about 200 times heavier.	
a. Muons are produced by several mechanisms and require photon energies greater than 212 MeV or proton energies greater than 140 MeV.	
b. Muons are not usually seen in significant amounts at machines with energies less than 1 giga electron-volt (GeV).	GeV = $1x10^9$ eV

Lesson Plan	Instructor's Notes
c. Muons travel mainly in the direction of the beam that produced them with very little deviation from the beam path. They are a concern directly downstream of targets, beam dumps, etc. Muons are ionizing particles and can deliver a very high dose.	
d. Muons lose energy only through ionization and are very penetrating. Large amounts of earth or steel are typically used to shield muons.	
7. Facility-Specific - Prompt	EO-06 IDENTIFY prompt radiation sources at site.
Identify facility-specific prompt radiation sources.	
B. Residual Radioactivation	EO-07 DEFINE radioactivation. EO-10 IDENTIFY activation products.
The process by which materials become radioactive is commonly referred to as "radioactivation" or simply "activation." Generally, energies above 10 MeV are needed to activate materials for particles other than neutrons.	
1. Residual radioactivity	
Activated materials emit radiation from radioactive decay after shut-off of the beam.	
2. Contaminated material versus activated material.	

Lesson Plan	Instructor's Notes
Contaminated materials are items with fixed or removable surface contamination.	
Activated material is radioactive material dispersed throughout the item and is not removable except through some type of destructive means as discussed below.	Give examples of destructive means.
a. Activated materials normally do not present a potential loose contamination hazard except during activities such as: ○ Grinding. ○ Burning. ○ Machining. ○ Handling coolant water filters. Target spallation may also create contamination without any physically destructive operation applied.	
b. Activated materials are normally controlled based on the external radiation dose rate.	
3. Activated materials	EO-08 IDENTIFY activation sources at the facility.
All materials located within an accelerator enclosure have the potential to be radioactivated if subjected to primary or secondary beams. Materials that may become radioactive include: ○ Any material within the accelerator enclosure.	

Lesson Plan	Instructor's Notes
○ Beamline components. ○ Air. ○ Cooling liquids and working fluids.	
4. Beamline components	
Beamline components may become radioactive depending on: ○ Nature of the material. ○ Proximity to the beam. ○ Beam characteristics.	Discuss how the capture cross-section differs with different material and how this affects activation.
Items that intercept a portion of the beam are most likely to be activated and contaminated. Among those items that have the highest probability for activation are:	
○ <u>Targets</u>: devices to intercept a portion of the beam for purposes of producing secondary beams.	See Glossary for definitions
○ <u>Beam dumps or stops</u>: used to absorb the beam.	
○ <u>Collimators and scrapers</u>: used to remove unwanted diffuse "halo" that often exists surrounding the central beam.	
○ <u>Septa and other magnets</u>: used to align and direct beams.	

Lesson Plan	Instructor's Notes
○ Cavities and beamline: the beamline piping and items such as resonating cavities, diagnostic devices, etc.	
5. Air	(Facility-Specific) Each facility should cover their radionuclides of concern, such as:
Air, dust, and other gases in the accelerator enclosure may be activated. Typically, the activation products are short-lived gaseous radionuclides of the elements in the air or particulate, in the case of dust particles. Examples are Oxygen-15 from Nitrogen-14 and Oxygen-16.	○ O-15 ○ N-13 ○ C-11 Cover facility's procedures for entering enclosure after beam shut-off.
6. Liquids	(Facility-Specific) Include likely facility locations.
a. Cooling water: used for cooling beamline components (activation products such as tritium (H-3), beryllium (Be-7) and possible pipe wear products or erosion of the pipe surfaces).	See Section VI, for methods to dispose of activated liquids.
b. Oil in vacuum pumps (beam line components).	
c. Cryogenic fluids: liquid helium and nitrogen are used frequently to cool components.	

Lesson Plan	Instructor's Notes
7. Facility-Specific	EO-08 IDENTIFY activation sources at site.
Facility should cover items that routinely become activated due to accelerator operation.	
8. Contamination	
Materials and activities that could create contamination concerns.	
a. <u>Surface coating</u>: such as paint, oxidation, and rust may present a contamination problem. Such coatings may be easily removable and may be present in areas not commonly accessed, such as beam dump vaults.	Cover each source as applicable to the facility.
b. <u>Compounds</u>: such as grease, sealants, gaskets, and anti-seize coatings may be activated depending on their composition. During maintenance, these compounds should be chosen carefully to minimize the production of contamination if possible. These materials may not be accessible until after components are disassembled; therefore, the need for carefully planned maintenance activities involving such compounds should be highlighted.	
c. <u>Impurities</u>: Impurities in cooling water systems can be a source of contamination. This source may be found in a filter/resin media system.	

Lesson Plan	Instructor's Notes
d. Activities: (Facility-Specific) routine work areas where contamination control must be considered:	Show picture of filter/resin media or bed as applicable.
◦ Machining of radioactive materials.	
◦ Cooling water filters.	
◦ Accessing beamline.	
◦ Maintenance.	
◦ Target removal.	
◦ Etc.	
C. Ancillary Sources	EO-09 IDENTIFY ancillary sources at site.
Accelerators employ devices to impart energy to particles or redirect them during the acceleration process. These devices may emit ionizing radiation while they are operating.	
1. Klystrons	
Klystrons provide power to accelerate charged particles. They emit X-rays during operation.	
2. Radiofrequency cavities	

Lesson Plan	Instructor's Notes
These devices accelerate charged particles using electromagnetic fields. Electrical discharges within the RF cavity cause photon emission.	
3. Electrostatic separators/Septa	Septa are also a high source of activation and residual radiation.
These devices split a particle beam into two beams using static electric fields. The high voltages associated with these devices cause electrons to accelerate in the vacuum within the beamline. They emit X-rays. Septa are also a high source of activation and residual radiation.	
4. Facility-Specific	
Location of facility-specific ancillary sources.	

Lesson Plan	Instructor's Notes
IV. TYPES OF CONTROLS	EO-11 IDENTIFY engineered and administrative controls at accelerator facilities.
Controls are used at accelerator facilities to protect personnel from exposure to ionizing radiation and other hazards including: ○ Electrical. ○ Mechanical. ○ Cryogenic. ○ Non-ionizing radiation.	EO-12 DESCRIBE each access mode at the facility and access the beam and beam containment including interlocks and warning devices and systems.
The design of an effective safety program incorporates a combination of: ○ Engineered controls. ○ Administrative controls. ○ Personnel protective equipment, e.g., respirators, protective clothing, etc. However, per 10 CFR 835.1001(c), the primary methods used shall be physical design features. Administrative controls and procedural requirements shall be employed only as supplemental methods to control radiation exposure.	
A. Engineered Controls Engineered controls include equipment and structures (passive or active) designed to protect personnel from hazards.	

Lesson Plan	Instructor's Notes
1. Passive engineered controls	
Once installed, passive engineered controls require no further action to perform their intended function. Passive engineered controls may include:	
a. <u>Radiation shielding</u>: such as concrete blocks, iron plates, lead bricks and earth berms.	
b. <u>Barriers</u>: such as fences, locked gates, and doors.	
c. <u>Facility-Specific</u>: facility-specific passive engineered controls.	
2. Active engineered controls	
Active engineered controls include devices that sense changing conditions and can trigger a safety action.	
a. <u>Safety interlock devices</u>. ◦ Area radiation monitors.	Show picture of facility safety interlock devices.
◦ Access sensors, magnetic and mechanical.	
◦ "Crash" or "scram" buttons.	

Lesson Plan	Instructor's Notes
b. Facility-specific: Facility-specific active engineered control devices.	Show active controls.
B. Administrative Controls. Programs and activities which personnel must implement to provide protection from hazards.	EO-11 IDENTIFY engineered and administrative controls at accelerator facilities.
1. Search and secure (sweep) procedures. These are procedures used to verify that no personnel remain in a beamline enclosure when it is being prepared to receive beam.	
2. (Facility-Specific) search procedures.	Explain facility-specific search procedures.
3. Controlled access procedures (including key controls). Procedures that allow personnel to access a beamline enclosure while it remains interlocked. There is no physical search of the area before the beam is restored.	
4. (Facility-Specific) controlled access procedures.	

Lesson Plan	Instructor's Notes
5. Radiological work permits (RWPs). RWPs provide written documentation of job descriptions, radiological conditions, and the required protective controls.	
6. Configuration control procedures. Procedures to ensure that important information about the configuration of a facility is accurate and that the configuration retains its functional purpose.	Discussed in IV. D. Configuration Control program, give examples.
7. Radiological monitoring programs. Provide assurance that the accelerator facility operates within the radiological safety design specifications and ALARA goals.	Discussed in Section V, Monitoring.
8. Warning indicators. ○ Status lights. ○ Alarms.	Show picture/apparatus of facility warning indicators.
C. Accelerator Facility Access Modes (Facility-Specific) The status or mode of accelerator enclosures regarding accessibility are covered below. Access modes change with the beam status.	(Facility-Specific) Use facility-specific terminology. EO-12 DESCRIBE each access mode at site.

Lesson Plan	Instructor's Notes
1. Normal or open access mode	
Beam area is not interlocked and beam cannot operate. Access to these areas is unrestricted after a radiation survey to identify and isolate areas of activation or contamination.	Explain that this classroom training does not by itself qualify trainees to make controlled access. Additional facility-specific training (hands-on practice factors?) is required. Describe how trainees may obtain this training.
2. Search & secure mode	
Operators physically search enclosures prior to beam operation to ensure that no personnel remain in the enclosure when it is secured for operation.	Discuss accountability for those who accessed.
3. Controlled access mode	
a. <u>Beam area</u>: Beam area has been searched and secured and remains interlocked, however, beam cannot operate.	
Limited personnel access is allowed. There is no search of area following the access.	
b. <u>Procedure</u>: Controlled access procedure (Facility-Specific).	Convey this by facility-specific demonstration or video.
4. Test mode	
Certain devices, (e.g., magnets) may be energized to allow testing. Limited personnel may access but must be aware of hazardous conditions (e.g. electrical power).	

Lesson Plan	Instructor's Notes
5. Exclusion mode Beam may be present. No access is allowed.	
D. Configuration Control Program	
The facility design must continue to meet its intended function while providing for adequate personnel safety. Configuration control ensures that only authorized changes are made and that any changes made continue to provide adequate personnel safety.	EO-13 DISCUSS site configuration control program.
1. Elements of a program Configuration control programs for accelerator facilities include: ○ Inventory and labeling of controlled devices. ○ Periodic inspections. ○ Procedures for change and/or restoration of configuration. ○ Testing to verify proper configuration.	
2. Structures and equipment. These must be maintained in a specific configuration to perform the desired safety function.	Show picture of a device that is labeled as a configuration controlled item.

Lesson Plan	**Instructor's Notes**
Examples include: ○ Radiation shielding. ○ Magnets. ○ Stops. ○ Detectors. ○ Interlocks and access system wiring.	
3. (Facility-Specific) configuration control procedures.	EO-11 DISCUSS site configuration control program.

Lesson Plan	Instructor's Notes

V. MONITORING

Monitoring refers to the checking, testing, and surveying of individuals, work areas, materials and equipment for ionizing radiation and radioactivity.

Monitoring for radiation at accelerators can be complicated. Special techniques and instrumentation may be necessary due to the existence of:

- Mixed radiation fields (photons, protons, neutrons, etc.).
- Pulsed beams.
- Very high energy radiation.
- High intensities of radiation (dose rates).
- Magnetic and RF fields.

A. Qualification of Monitors

(Facility-Specific) Discuss facility requirements for qualifications to perform surveys.

Monitoring is only performed by Radiological Control Personnel or others who are specifically trained and qualified to perform monitoring.

B. Area Monitoring

Monitoring of areas at accelerator facilities refers to monitoring for radiation and contamination using fixed

EO-15 STATE purpose of initial entry survey.

Lesson Plan	Instructor's Notes
and portable instruments. Monitoring may include measuring for: ○ Prompt radiation. ○ Residual radiation. and includes: ○ Work areas. ○ Surfaces. ○ Water. ○ Air. ○ Non-work areas outside of enclosures.	
C. Prompt Radiation Monitoring Prompt radiation monitoring is to ensure radiation levels outside of accelerator facilities are maintained below regulatory limits to workers and the general public, and as a means to detect deficiencies in beam containment.	(Facility-Specific) Each facility should discuss facility-specific instruments, settings, locations, and consequences of tampering.
1. Instrumentation Prompt radiation surveys may utilize fixed and portable instruments.	
2. Pulsed radiation Prompt pulsed radiations must be measured with specialized survey instruments. Ion chambers are typically used.	(Facility-Specific) Show example of instrument.

Lesson Plan	Instructor's Notes
3. Neutron radiation.	
Neutron monitoring is complicated and should be performed by an individual qualified to perform neutron surveys.	
D. Residual Radiation	Define removable and fixed contamination if not covered in previous training.
Radioactive materials may be found at accelerator facilities in the form of: ○ Removable contamination. ○ Fixed contamination. ○ Activated materials. ○ Volume contamination.	
1. Residual radiation monitoring	
Residual radiation is typically monitored with portable instruments and contamination swipes. Types of monitoring may include: ○ Work areas. ○ Items/materials. ○ Operational systems.	
2. Monitoring instruments	(Facility-Specific) Each facility should discuss the locations and instruments used for monitoring induced activity.
Special instruments may be needed for monitoring residual activity in materials depending on: ○ Nature of material. ○ Physical form (i.e., liquids).	

Lesson Plan	Instructor's Notes
3. Work areas Types of work area surveys include: ○ Radiation dose rate surveys. ○ Loose surface contamination surveys. ○ Air sampling, including continuous air monitoring.	(Facility-Specific) Each facility should discuss their work area monitoring program.
4. Items/materials monitoring (Facility-Specific) The purpose of monitoring materials is to ensure radioactive materials are identified and controlled within controlled areas. All items/materials must be surveyed prior to removal from areas of potential activation/contamination. Typically this includes any material inside the beam enclosures, targets and shielded structures.	EO-17 STATE site requirements for removing material from beam enclosures.
5. Cooling water and other systems. Typical monitoring may include: ○ Sampling component cooling water. ○ Monitoring filter media.	(Facility-Specific) Each facility should discuss their environmental monitoring program.
E. Environmental Monitoring Environmental sampling/monitoring may include: ○ Prompt radiation levels (neutrons, skyshine, muons, etc.).	(Facility-Specific) Each facility should discuss their monitoring program, as applicable to the target audience.

Lesson Plan	Instructor's Notes
○ Radiation levels at site boundary from storage areas, etc.	
○ Sampling of exhausted air from beam housings.	
○ Surface/ground water (on and off site).	
○ Monitoring of radiation levels at site boundary.	
○ Soil/vegetation/deposition near liquid discharges and air exhaust.	
F. Personnel Monitoring	Review the general dosimetry program if not covered in other training.
1. Personnel dosimetry monitoring (Facility-Specific)	
2. Personnel contamination monitoring at electron and proton accelerator facilities	
Electron facilities typically will have a lower incidence of contamination than proton facilities due to the higher neutron flux produced by proton collisions.	
3. Locations (Facility-Specific)	Review facility-specific information.
Discuss locations requiring personnel radiation exposure and contamination monitoring.	

Lesson Plan	**Instructor's Notes**
4. Jobs/tasks (Facility-Specific)	Review facility-specific information.
Jobs/tasks that may require personnel contamination monitoring include:	
○ Machining and welding of activated materials.	
○ Handling water used to cool accelerator components.	
○ Handling sealed sources suspected of leakage.	
○ Entering target rooms.	
○ Accidental releases.	

Lesson Plan	Instructor's Notes

VI. RADIOACTIVE WASTE ISSUES

A. Sources of Radioactive Waste

The radioactive waste from an accelerator facility tends to be mostly machine components or experimental equipment used in or near the particle beam. These components are often of copper, iron (steel), and aluminum. Other items or tasks contributing to radioactive waste are:

- Shielding blocks (iron, lead, or concrete).
- Coolant.
- Maintenance/modifications.
- Cleaning materials.

1. Shielding blocks (iron, lead, or concrete)

   Shielding blocks are quite large and their highest activity is usually below the surface. Shielding blocks showing several rad/hr at the surface may have no removable (wipeable) surface contamination and can be stored without contamination problems. Whenever possible, shielding blocks should be stored for reuse where dose is not a problem.

2. Coolants

   If possible, cooling water should be cleaned and recirculated/reused. The use of "pure" water minimizes the radioactivation problems caused by impurities.

Lesson Plan	Instructor's Notes
It may be desirable to dispose of water before the tritium concentration becomes too high. Some possibilities for disposal are:	Discuss facility-specific limits, as applicable.
a. <u>Sanitary sewer</u>: Disposal through the sanitary sewer. This may be regulated by several agencies, such as DOE, NRC, EPA, and State and local water pollution control boards. Their regulations will set concentration limits and, perhaps, annual limits.	
b. <u>Evaporation</u>: The water can be evaporated in engineered evaporation systems.	
c. <u>Solidification</u>: The water can be used to make concrete for solidification of other liquid wastes.	
d. <u>Decay</u>: Water from a small-volume, high concentration system could be transferred to a large-volume, low concentration system where it can decay safely.	
e. <u>Ion exchange resins and filters</u>: These are used to remove impurities from recirculating cooling water systems and can accumulate radionuclides such as Be-7, Na-22, Mn-54, and Co-60.	Insert facility-specific radionuclides of concern.

Lesson Plan	Instructor's Notes
3. Maintenance/modifications	
Radioactive waste can be generated by maintenance and modification of beamline components. Waste from this source may include:	
a. Compactables: Compactables such as rags, anticontamination clothing, surface coverings, etc.	
b. Tools, equipment, components: Items that are no longer of use. These may consist of materials contaminated by the transfer of activated radioactive material to their surface or items that are radioactivated from being in the beamline.	
4. Soils	
Soils surrounding buried beam dumps may become activated. These can become classified as radioactive waste when facilities are modified or decommissioned.	
B. Minimizing Radioactive Waste	EO-18 IDENTIFY methods to minimize radioactive waste at the facility. Ask participants for methods to minimize waste. Discuss pros and cons of saving or discarding material decontamination, storage, reuse, etc.
Because of the difficulty and cost in disposing of radioactive waste, special care should be taken to minimize waste generated.	

Lesson Plan	Instructor's Notes

- Avoid bringing unnecessary material into accelerator enclosures.

- Designate an area to store contaminated tools for reuse.

- Plan your work so that, whenever possible, construction and clean maintenance can be done in a clean area.

- Do not leave unnecessary tools and equipment in accelerator enclosures.

- Reuse items

C. Mixed Waste

Mixed waste is waste that is classified as hazardous in accordance to the Environmental Protection Agency (EPA) AND is also radioactive. There is presently no approved method to dispose of mixed waste, and long-term storage is required.

1. Sources of mixed waste.

   Common examples of waste materials at accelerators are:
   - Lead (shielding, batteries, etc.).
   - PCBs
   - Cadmium.
   - Acids.
   - Bases.

Lesson Plan	Instructor's Notes
○ Solvents and degreasers.	
D. Minimizing Mixed Waste	Ask participants for methods to minimize mixed waste.
○ Use non-hazardous cleaning materials for decontamination.	
○ Segregate "radioactive only" from "hazardous only" at the source.	
○ Explore the use of non-hazardous materials.	

Lesson Plan	Instructor's Notes
VII. ABNORMAL CONDITIONS	EO-19 IDENTIFY facility alarms and responses to abnormal conditions.
To properly deal with unexpected abnormal situations occurring in an accelerator facility, a well-thought-out responses program and personnel trained to execute the responses should be in place. Abnormal conditions may include:	
A. Loss of Beam Containment (Facility-Specific). Discuss facility-specific actions. B. Radiation Overexposure (Facility-Specific) Discuss facility-specific actions.	Discuss the consequences of design basis accidents at the facility. Include facility-specific Emergency Action Levels and Protection Actions in accordance with the site hazard assessment. Discussion of potential cause of abnormal conditions.
C. Fires (Facility-Specific). Discuss facility-specific actions.	
D. Loss of Radioactive Material (Facility-Specific). Discuss facility-specific actions.	
E. Facility Alarms (Facility-Specific). Discuss facility-specific actions.	
F. Safety Assessment Document (SAD). DOE Order 5480.25 requires a SAD for accelerators. The SAD provides analysis of the potential accidents	

Lesson Plan	**Instructor's Notes**
that can be experienced at a particular facility and outlines the accelerator's safety envelope.	

Lesson Plan	Instructor's Notes
VIII. LESSONS LEARNED	
Previous incident reports.	

Lesson Plan	Instructor's Notes

IX. REVIEW OF COURSE OBJECTIVES

The participant will be able to SELECT the correct response from a group of responses that verifies his/her ability to:

EO-01 IDENTIFY uses for accelerators.

EO-02 STATE the type(s) of accelerators at the facility.

EO-03 STATE type(s) of particles accelerated.

EO-04 DEFINE prompt radiation.

EO-05 DISCUSS the biological affects of radiation characteristics of accelerators.

EO-06 IDENTIFY prompt radiation sources at facility.

EO-07 DEFINE radioactivation.

EO-08 IDENTIFY activation sources at facility.

EO-09 IDENTIFY ancillary sources at facility.

EO-10 IDENTIFY activation products.

EO-11 IDENTIFY engineer and administrative controls at accelerator facilities.

EO-12 DESCRIBE each access mode at facility and access to beam and beam containment including interlocks and warning devices and system.

Lesson Plan	Instructor's Notes
EO-13 DISCUSS site configuration control program.	
EO-14 DISCUSS special radiological surveys and techniques.	
EO-15 STATE purpose of initial entry survey.	
EO-16 DISCUSS special instruments and measurement techniques.	
EO-17 STATE site requirements for removing material from beam enclosure.	
EO-18 IDENTIFY methods to minimize radioactive waste at the facility.	
EO-19 IDENTIFY facility alarms and responses to abnormal conditions.	

GLOSSARY

Accelerator: A device employing electrostatic or electromagnetic fields to input kinetic energy to molecules, atomic, or subatomic particles, and capable of creating a radiological area.

Access control system: Engineered or administrative systems that manage radiation dose to personnel by limiting personnel entry.

Actinide Transmutation: Transformation of actinides through neutron activation.

Activity: The rate at which a source emits radiation is called its activity. Activity is measured in terms of the number of disintegrations that take place every second. The unit for activity used at DOE sites is the curie (Ci). One curie is equal to 37 billion (3.7×10^{10}) disintegrations per second.

Annual Limit on Intake (ALI): Means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. (see 10CFR 835)

Attenuation: The process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux intensity.

Beam: A flow of electromagnetic or particulate radiation that is either collimated and generally unidirectional, or divergent from a small source but restricted to a small solid angle.

Beam scrapers: Beam scrapers remove particles that have wandered from the central area of the beam.

Bremsstrahlung: Secondary photon radiation produced by deceleration of charged particles passing through matter.

Collider: An accelerator in which two opposed beams of particles collide head-on.

Continuous Air Monitor (CAM): Instrument that continuously samples and measures the levels of *airborne radioactive materials* on a "real time" basis and has alarm capabilities at preset levels.

Cryostat: An instrument or device that maintains low temperature for superconducting magnets.

Cyclotron: A cyclic accelerator in which the charged particles spiral outward from the center of the machine as they gain energy.

Decommissioning: The process of closing and securing a nuclear facility, or nuclear materials storage facility, so as to provide adequate protection from radiation exposure and to isolate radioactive contamination from the human environment.

Depleted Uranium: Uranium having a percentage of uranium-235 smaller than the 0.7% found in natural uranium.

Derived Air Concentration (DAC): The airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2,000 hours (assuming a breathing volume of 2,400 m^3).

Detector: Any device that can detect the presence of an energetic electromagnetic radiation particle or nuclear fragment and measure one or more of its properties.

Electromagnetic Radiation: A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from *X-rays* and *gamma rays* of short wavelength, through the ultraviolet, visible and infrared regions, radar and radio waves of relatively long wavelength.

Enclosed Beam: All possible X-ray beam paths are fully contained in protective enclosures so that no part of the body can intercept the beam during normal operation.

Electron volt: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt.

Exclusion Area: Any area to which access is prohibited for the purposes of protection of individuals.

GLOSSARY (continued)

Fail-Safe: A design feature built into a system or system component so that the most likely mode of failure causes the production of X-rays to be turned off. If fail-safe design is not possible or cost-effective, the system or system component should be designed so that no single failure will cause unsafe operation.

Interlock: A safety device that automatically renders an area safe from prompt radiation when the device is actuated.

Linear accelerator: A device that accelerates charged particles along a straight line.

Mixed Waste: Waste containing both radioactive and hazardous components as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.

Muon: An elementary particle apparently identical to the electron except for being 200 times heavier.

Neutron: Elementary particle with a mass approximately the same as that of a hydrogen *atom* and electrically neutral.

Nucleus: The small, central, positively charged region of an *atom* that carries essentially all the mass.

Pion: A cosmic particle with a mass about 273 times that of an *electron* and a half-life of 2/100,000,000 (2×10^{-8}) of a second. Positive, negative, and neutral pions exist.

Primary Beam: *Radiation* that passes through the window, aperture, cone, or other collimating device of the source housing. Sometimes called *useful beam*.

Prompt radiation: Radiation resulting from the accelerator beam or the interaction of the accelerator beam with surrounding matter that ceases shortly after the beam is removed. Activation products and area contamination are not considered prompt radiation.

Proton: An elementary nuclear particle with a positive electric charge and an atomic weight of approximately one.

GLOSSARY (continued)

Radiation: Radiation refers to the emission and propagation of waves or particles through matter or space. Matter absorbs energy from radiation. In a microwave oven, for example, food absorbs energy from microwave radiation and is heated and cooked.

Radiation alarm system: A system providing notification, including activation of a radiation warning system, that a radiation condition exists that exceeds preset limits. An alarm system may initiate mitigating action.

Radiation warning light: A system that alerts personnel to a potential or actual change in the radiation level in a working environment. A warning system does not initiate mitigating actions.

Radioactivation or Activation: The process of producing a radioactive material by bombardment with neutrons, protons, or other nuclear particles.

Redundancy: Duplication or repetition of elements in electronic or mechanical equipment to provide alternative functional channels in case of failure.

Scattered Radiation: *Radiation* that, during passage through matter, has been deviated in direction. It may have been modified also by a decrease in energy.

Scram switch: An interlock that is intended for emergency use only. Scram switches are usually placed within exclusion areas where personnel may be caught during pre-start-up or actual operations.

Search: (This is commonly referred to as a sweep.) A physical inspection carried out under controlled conditions to ensure that no personnel are left inside exclusion areas.

Septa: An area associated with an accelerator beam line where the beam is split into two or more beams, normally through the use of magnets. This area is prone to radioactivation due to the interaction of the beam with structural materials.

Spectra: A visual display, a photographical record, or a plot of the distribution of the intensity of radiation at a given kind as a function of its wavelength, energy, frequency, momentum, mass, or any related quantity.

Spallation: A term used to denote a nuclear reaction induced by high-energy bombardment and involves the ejection of two or more particles.

Superconductivity: The ability of some materials to carry an electric current with no power loss, owing to the complete absence of electrical resistance. To date, superconductivity has been found only in a few metals and alloys and at very low temperatures.

Synchrotron: An accelerator in which the energy of charged particles is increased as they travel around a circular orbit of fixed radius.

Useful Beam: *Radiation* that passes through the window, aperture, cone, or other collimating device of the source housing. Sometimes called *primary beam*.

Volt: The term potential difference symbolized by V is defined as the work per unit charge done in moving a charge from one point to the other.

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(Part 3 of 3)

Radiological Training for Accelerator Facilities

Student's Guide

Coordinated and Conducted
for
Office of Environment, Safety & Health
U.S. Department of Energy

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Table of Contents

TERMINAL GOAL:

At the end of this course, the participant should be able to demonstrate a basic understanding of the characteristics of accelerators and the radiological precautions for working at an accelerator facility.

ENABLING OBJECTIVES:

The participant will be able to:

EO-01	IDENTIFY uses for accelerators.
EO-02	STATE the type(s) of accelerators at the facility.
EO-03	STATE type(s) of particles accelerated.
EO-04	DEFINE prompt radiation.
EO-05	DISCUSS the biological effects of radiation characteristic of accelerators.
EO-06	IDENTIFY prompt radiation sources at the facility.
EO-07	DEFINE radioactivation.
EO-08	IDENTIFY activation sources at the facility.
EO-09	IDENTIFY ancillary sources at the facility.
EO-10	IDENTIFY activation products.
EO-11	IDENTIFY engineered and administrative controls at accelerator facilities and personnel protective equipment.
EO-12	DESCRIBE each access mode at the facility and access to beam and beam containment including interlocks and warning devices and systems.
EO-13	DISCUSS site configuration control program.
EO-14	DISCUSS special radiological surveys and techniques.
EO-15	STATE purpose of initial entry survey.
EO-16	DISCUSS special instruments and measurement techniques.
EO-17	STATE site requirements for removing material from beam enclosure.
EO-18	IDENTIFY methods to minimize radioactive waste at the facility. (Facility-Specific)
EO-19	IDENTIFY facility alarms and responses to abnormal conditions. (Facility-Specific)

COURSE CONTENT:

1. History and Uses of Accelerators.

2. Facility Description.

3. Radiological Concerns.

4. Types of Radiological Controls for Accelerator Facilities.

5. Monitoring at Accelerator Facilities.

6. Radioactive Waste Issues.

7. Abnormal Conditions at Accelerator Facilities.

8. Lessons Learned.

9. Summary and Review.

I. HISTORY AND USES OF ACCELERATORS

EO-01 IDENTIFY uses for accelerators.

A. Definition

Accelerators are devices employing electrostatic or electromagnetic fields to input kinetic energy to molecules, atomic or subatomic particles and capable of creating a radiological area.

Overview

Accelerators were originally designed to study (research) the structure of matter.

Accelerators today are used not only for basic research purposes, but also for many other applications.

Accelerators are to particle physics what telescopes are to astronomy, or microscopes to biology. These instruments all reveal and illuminate worlds that would otherwise remain hidden from our view. They are the indispensable tools of scientific progress.

The earliest accelerators were simple vacuum tubes in which electrons were given an increase in energy by the voltage difference between two oppositely charged electrodes. From these evolved the Cockcroft-Walton and Van de Graaff machines, larger and more elaborate, but using the same principle. The modern example of this type of device is the linear accelerator, a sophisticated machine used in many scientific and medical applications. All such straight-line accelerators suffer from the disadvantage that the finite length of flight path limits the particle energies that can be achieved.

The great breakthrough in accelerator technology came in 1930 with Ernest O. Lawrence's invention of the cyclotron. In the cyclotron, magnets guide the particle along a spiral path, allowing a single electric field to apply many cycles of acceleration. Soon unprecedented energies were achieved, and the steady improvement of Lawrence's simple machine has led to today's synchrotrons, whose endless paths allow electrons, positions, and protons to gain huge energies by passing millions of times through the electric fields that accelerate them.

The Beginning of Modern Physics

In 1911, Hans Geiger and Ernest Marsden performed an experiment that was the foundation of modern particle physics. At the urging of the great physicist Ernest Rutherford, they used a radioactive source to shoot alpha particles at a wafer-thin gold foil and detected the scattered alphas by watching them hit a phosphorescent screen. At the time, alpha particles were known to be related to helium atoms and to be much heavier than electrons, but the nature of the atom was the subject of speculation. J. J. Thomson, the discoverer of the electron, believed that the negatively charged electrons in an atom were embedded in an unknown way in a cloud of counterbalancing positive charge, much like raisins in a plum pudding.

By studying how the alpha particles scattered off the gold foil, scientists hoped to learn something of the nature of the gold atoms. According to Thomson's plum-pudding model, it was expected that the alpha particles should pass through with only small changes of direction because neither the electrons, which were too light, nor the positive charge, which was too diffusely distributed, could exert enough force on the alphas to knock them noticeably off-course. However, Geiger and Marsden found that some of the alpha particles were deflected at large angles, and a few actually reversed direction altogether.

By analyzing the distribution of scattered alpha particles, Rutherford arrived at the modern picture of the atom in which the electrons orbit a tiny central nucleus, as in a miniature solar system. In the Geiger-Marsden experiment, most of the alphas go straight through the empty spaces but occasionally one will get close enough to a dense, heavy nucleus that electrical repulsion between the two will push the alpha off its path. This revelation of the atom as a tiny mechanical system, consisting of electrons and a nucleus, was the beginning of modern atomic physics.

B. Need for Accelerators

The reason accelerators are of use in basic research can be described in terms of "black box" experiments. Early studies in the structure of atoms approached the problem much like you may approach the question of what is in a box that you cannot look into. You can fire "small bullets" at the box and observe the effects. Did the bullet pass through? Did the bullets form a "shadow" pattern? Were some of the bullets deflected? Did the bullets knock out pieces (particles). The Geiger-Marsden experiment (the discovery of the nucleus) used alpha particles as the "tiny bullets."

In the early 1900s, radioactive particles could be obtained only from materials found in nature. The studies that physicists wanted to perform required both higher intensities and higher energies than were obtainable from the natural sources. The ability to vary energy and intensity to suit a particular experiment was also desirable. In addition, there was a need to know precisely the composition of the beam of particles, where the beam was hitting the target, and the spread in energy at the target. In other words, what was needed was control, which is the essence of the experimental method.

In the 1930s, scientists began to build machines that produced the needed degree of control. These machines were called accelerators.

C. The Development of the Accelerator

The source of particles for the first accelerators was the simplest atomic element, hydrogen. Hydrogen atoms are composed of a proton with a positive charge and a much lighter electron with a negative charge. Since opposite electrical charges attract, there is a force holding these two particles together in a normally stable configuration, somewhat analogous to the moon in its stable orbit around the earth. If hydrogen gas and a few extra electrons are introduced into a chamber where there is a positive electrical charge on one side of the chamber and a negative electrical charge on the other side, the result will be collisions between electrons, protons, and atoms that knock apart many of the atoms. When this happens, we say that the hydrogen gas has been ionized. The free protons produced by such ionization are used as the particles to be accelerated.

These free protons are now introduced into another chamber where again there is an electrical force on them. This force *accelerates* the protons, i.e., increases their velocity (speed).

The kinetic energy (the energy of motion) of a particle (at least for velocities much less than the speed of light) is given by the equation:

$$KE = \frac{1}{2} mv^2$$

where KE = the kinetic energy,
m = the mass of the particle, and
v = the velocity of the particle.

The acceleration of the proton by this electrical force also increases the energy of the proton.

The amount of acceleration is determined by the potential difference measured in volts (V) in this electrical field. One electron volt (eV) is the energy gained by an electron accelerated through an electric potential of 1 volt. Thus, if a proton is accelerated across a gap by means of a 10,000 volt, or 10 kilovolt (kV), potential difference, it is said to have gained 10,000 electron volts (10 keV) of energy after crossing the gap.

Ten keV was a potential easily achieved, but scientists wanted to accelerate particles to many times this energy. One way to accomplish this was to apply 10 kV potential to each of many gaps and have the particle traverse these gaps one after another, gaining 10 keV in energy for each gap traversed. Alternatively, a voltage many times larger than 10 kV might be applied to a single gap.

D. Van de Graaff Generator

One of the first machines to produce laboratory-accelerated particles was the Robert Van de Graaff generator, an electrostatic accumulator that produces large potential differences essentially by rubbing. In 1929, Van de Graaff built a pilot machine capable of generating 80,000 volts (80 keV). In 1931, a 1.5 million-volt (MeV) machine was constructed at Princeton at a total material cost of only about $100. The machine consists of a polished metal sphere and a moveable belt. The function of the belt is to carry an electrical charge up to the sphere where it is stored. This process can be continued until a very high potential is developed in the sphere.

Once the sphere of a Van de Graaff machine is charged to its maximum voltage, the protons or other particles to be accelerated are ejected from an ion source in the high-voltage terminal into the accelerating tube. They are then accelerated by the potential difference between the sphere and the grounded end of the tube.

Many machines have since been built following the general principles of the first Van de Graaff mode. There are two factors that can limit the maximum potential of the sphere in a Van de Graaff machine. One is the leakage current across the insulators and through the air (or other gas) surrounding the sphere; the other is gaseous breakdown. The leakage limit is reached when the leakage current, which increases with the voltage, becomes equal to the current carried by the belt. The breakdown limit is reached if a spark in the gas discharges the sphere.

By placing accelerators in series (accelerators placed one after another), it is possible to achieve much higher particle energies than with just one accelerator.

In present-day research, the Van de Graaff generator serves two purposes. One is as a source of particles for research in low-energy nuclear physics; the second is to inject particles into much larger accelerators.

A state-of-the-art accelerator, 25 MeV, was built and operated at the Daresbury Laboratory in the United Kingdom.

E. Cockcroft-Walton Accelerator

In 1932 in England, John D. Cockcroft and Ernest T.S. Walton constructed what is called a linear accelerator using a high-voltage source to accelerate protons through 700,000 volts (700 keV). In 1932, they first used these particles to bombard lithium and split it into two helium nuclei. Cockcroft and Walton were awarded the Nobel Prize in 1951.

The Cockcroft-Walton accelerator and the van de Graaff generator have since been refined and replaced as sources of very high-energy particles; however, they retain their importance in two respects:

- They provide injection systems for higher-energy circular accelerators, and
- They have been improved and extended to provide higher-energy linear accelerators.

From the laboratory-sized generator of Cockcroft and Walton, the linear accelerators have grown to the 2-mile length of the Stanford Linear Accelerator (SLAC).

F. Linear Accelerators

In its simplest form, a linear accelerator consists of a series of electrodes. Alternate electrodes are connected electrically to each other, and holes bored through them permit the passage of the beam.

The electric field created by the electrodes exerts a force on the charged particles and accelerates them.

Linear accelerators have a number of significant advantages. Chief among them is the ease with which particles may be introduced at one end and extracted at the other. But to achieve very high energies, accelerators must be of great length and very high voltages because the particles must be pushed by large forces for long periods of time.

At Stanford University, a 1 billion volt (1-GeV) linear electron accelerator was completed in 1951. In a series of experiments over a period of years, the charge distributions on the nuclei were measured for many elements. In recognition of the importance of this series of experiments, Professor Hofstadter was awarded the Nobel Prize in Physics in 1961.

Large linear accelerators are of two types:

- the drift tube and

- the wave guide.

- Drift tube accelerator: In the drift-tube accelerator, the particle is accelerated through gaps between sections of a hollow conducting cylinder. When the particle crosses a gap, it is accelerated and the voltage oscillates so that when the particle reaches the next gap, it is accelerated again. Since the frequency of the voltage is kept constant, sections of the tube must be of different lengths as the particle accelerates.

- Wave guide accelerator: The wave guide accelerator, invented in 1947 by D.W. Fry, uses long wavelength electromagnetic waves guided through a hollow conductor. Since electrons of moderate (about 2 MeV) energy already travel with nearly the speed of light, they can keep up with the wave and thus ride the force of the electric-vector part of the wave somewhat as a surfer can ride an ocean wave.

G. Lawrence and the Development of the Cyclotron

The attempt to reach higher energies than were available with the devices of the early days led Ernest O. Lawrence of the University of California to propose the first cyclotron. The idea was simple. Instead to trying to accelerate the particles in one pass through, it was proposed that many small accelerations be used so that their sum would be what was desired. The idea was to use a magnetic field to make the charged ion move in a circular path.

Lawrence succeeded in substituting a circular race track for the straight-line track of the linear accelerator. Each time the particle went around, it could be accelerated a little bit thus attaining energies above that used in previous accelerators and thus with comparatively low voltages. In describing the first cyclotron, Lawrence and Livingston wrote in 1932 that “experimental difficulties go up rapidly with increasing voltage." This first device, barely 1 foot across, produced 1,200,000-volt (1.2 MeV) protons.

Cyclotrons also serve as tools in producing radionuclides and elements previously unknown to scientists. This is accomplished by irradiating a target of natural materials with protons, deuterons, (a nucleus of deuterium or "heavy hydrogen” consisting of one proton and one neutron") or alpha particles from a cyclotron.

The knowledge gained in these early experiments was significant in the development of the early atomic weapons. Plutonium, element 94, was first obtained by bombarding Uranium-238 with deuterons in the University of California cyclotron built by Lawrence.

H. Synchrotrons

By the late 1930s, still higher energies were needed. Physicists were beginning to think of more advanced machines to achieve these higher energies. The outbreak of World War II shelved these plans, as scientists became involved in the Manhattan Project, which built the first atomic bomb. With the return of peace, scientists began to think again of higher energies.

In 1945, V. Veksler in Moscow and E. M. McMillan in Berkeley independently introduced the principle of the synchrotron, a fixed-radius circular accelerator. The idea was to vary both the electric field frequency and the magnetic field at the same time. Veksler and McMillan demonstrated that the orbits could maintain their stability in this process. Since the magnets of the synchrotron need be placed only at the fixed radius of the particle orbit, the width of the magnet pole face is much smaller than for magnets of varying radii machines.

The early synchrotrons had four huge C magnet sections with gaps between them for injecting, accelerating, and targets. As the particle's energy (and hence its speed) increases, the frequency of the accelerating field is increased and the magnetic field is made stronger. The choice of the particle to be accelerated (i.e., electron, proton, positron, heavy ion) depends on the purpose, such as research isotope production, bremsstrhlung production, or fusion.

The limiting factor with the fixed-frequency synchrotron was its inability to compensate for the slowing down of the revolution frequency of particles once they had been accelerated to near the speed of light. To overcome this, scientists hit upon the idea of developing a radio-frequency power supply in which the frequencies would decrease with time to match exactly the slower revolutions of the particles.

To do this, a machine was designed that operated in a pulsating manner (protons being accelerated in bursts). Unlike the fixed-frequency cyclotron, which can continuously accelerate a stream of particles, the new machine, the synchrocyclotron, has to push one group of protons through an entire cycle, from the initial highest frequency to the final lowest one, before it can begin accelerating a new group.

The first synchrocyclotron was the one at Berkeley, and it began operation in 1946. Exciting experiments, not possible with lower energy machines, were quickly begun.

There is not a theoretical limit on the energy of a synchrocyclotron. There is, however a practical limit from the point of view of economics. As the desired energy increases, so must the radius of the magnet. As this radius increases, the magnet's area increases as the square of the radius and its cost may increase by a factor almost equal to the cube of the radius. Thus, the cost rises much too steeply for the synchrocyclotron technique to be used to reach energies in the billion electron (GeV) region.

Accordingly, in seeking such energies, scientists tried another technique. This was to develop machines in which the magnetic field rises in step with the momentum of the particles being accelerated. This keeps the particles moving in a circle of virtually constant radius rather than in the widening spirals of cyclotron and synchrocyclotrons. The advantage is that it eliminates the entire center section of the magnet, with resultant cost savings.

The size of the magnet in a particle synchrotron is determined by two factors. One is the energy desired, which determines how wide a circle the particles must traverse. The other is the degree to which the particles are concentrated or "focused" in the magnetic field. This determines the size of the vacuum chamber.

The first particle synchrotron completed was the Cosmotron at Brookhaven National Laboratory. It accelerated protons to 2.3 GeV in 1952 and later to 3 GeV.

I. Colliders

Until 30 years ago, all accelerators were so-called fixed-target machines in which the speeding particle beam was made to hit a stationary target of some chosen substance. But in the early 1960s, physicists had gained enough experience in accelerator technology to be able to build colliders in which two carefully controlled beams are made to collide with each other at a chosen point. Several colliders exist around the world today, and the technology for them is by now well established.

Colliders are more demanding to build, but the effort pays off handsomely. For example, in a fixed-target machine, most of the energy of the projectile particle is locked up after impact on the target, in continued forward motion of the debris. In a collider, on the other hand, two particles of equal energy coming together have no net motion, and collision makes all their energy available for new reactions and the creation of new particles.

Most metals conduct electric current more readily as they are cooled. But a few special metals and alloys lose all trace of electrical resistance at very low temperatures. At the very low temperatures in superconductors, currents flow unhindered and will persist forever once started.

The enormous potential of this discovery, made by the Dutch physicist Kamerlingh-Onnes in 1911, is easy to see. In electrical devices, the barrier to higher efficiency is power loss. Immersion in cryogenic liquid is the only way to achieve the extremely low temperatures needed for superconductivity to occur, and for this reason it remained merely a laboratory curiosity until recently.

The rewards of this new technology for high-energy physics were so great that an enormous effort was made to realize superconductivity on a large scale. The effort paid off in 1983, when protons first passed through liquid-helium-cooled magnets of the Fermilab Tevatron.

Superconducting magnets are not only more efficient than conventional ones but, with higher currents, can generate stronger magnetic fields. This allows accelerators to achieve huge energies using rings that are not impractically large.

J. Purpose and Uses

EO-01 IDENTIFY uses for accelerators.

Accelerators have contributed many new and exciting insights into the structure of matter.

Accelerators are designed for a variety of purposes, such as research into the nature of matter, production of radioisotopes (such as tritium), generation of bremsstrahlung for radiography and radiation therapy, induction of fusion, pumping for lasers, detoxification of hazardous waste, actinide transmutation, production of synchrotron radiation, sterilization of food and surgical equipment, and industrial manufacturing. Each purpose dictates a particular energy range and choice of particle to be accelerated **-** electrons, protons, or nuclei of heavier elements.

II. FACILITY DESCRIPTION

A. Types of Accelerators in Use at Facility (Facility Specific)

EO-02 STATE the type(s) of accelerators at the site.

Electrostatic accelerators

- Cockcroft-Walton
- Van de Graaff, Tandem Van de Graaff

Linear accelerators (Linac)

- Resonant cavity (standing wave).
- Traveling wave.

Cyclic accelerators

- Synchrotron.
- Cyclotron.
- Betatron.

B. Types of Particles Accelerated at the Facility (Facility Specific)

EO-03 STATE type(s) of particles accelerated.

C. Facility Layout and Description of Areas/Components (Facility Specific)

- Injectors.
- Target areas.
- Experimental areas.
- Beamlines.
- Control room.
- Shielding structures.

III. RADIOLOGICAL CONCERNS

A. Prompt Radiation

EO-04 DEFINE prompt radiation.

EO-05 DISCUSS the biological effects of radiation characteristics of accelerators.

EO-06 IDENTIFY prompt radiation sources at the facility.

Includes the accelerated particle beam and the radiation produced when the beam interacts with matter or changes direction. It is only present when a beam is operating or being accelerated.

1. Primary beam

The primary beam consists of accelerated charged particles prior to any interactions.

It is the most intense form of radiation present at an accelerator facility and is made inaccessible to personnel through engineering design and administrative controls. Direct exposure to a particle beam can result in a potentially dangerous, or even lethal, dose of radiation.

2. Secondary beam

Secondary beam is produced by interaction of the primary beam with targets or beamline components. Some accelerators produce a secondary beam for use. Beam spray (secondary radiation) can be produced by interaction with targets or beamline components. This causes elevated radiation in the vicinity. The secondary beam is less intense than and usually less energetic than the primary beam and may consist of:

- Electromagnetic radiation.
- Neutrons.
- Charged particles.

3. Skyshine

EO-14 DISCUSS special radiological surveys and techniques.

Skyshine is the radiation scattered from air molecules. Accelerator-produced skyshine is usually neutron radiation, scattered after emerging more or less vertically from the shielded enclosure. It can cause elevated radiation fields at ground level considerable distance from the source.

Due to typical facility design, photon skyshine is usually less of a problem but is a consideration, particularly where radioactive materials are stored.

4. Electromagnetic radiation

Electromagnetic radiation (photons) may be classified into several categories.

<u>High-energy photons</u> (X- rays and gamma rays) may be produced by several mechanisms. When electrons are decelerated, they emit bremsstrahlung "braking" radiation. These are classified as X- rays. Also, the decay of subatomic particles may produce photons.

<u>Electromagnetic cascades</u> can develop when an electron (or positron) emits a photon that has sufficient energy to produce an electron-positron pair. These particles produce more photons, etc. The chain of interactions continues until the photons no longer have sufficient energy for pair production (about 1 MeV).

<u>Synchrotron radiation</u> is a by-product of the acceleration process. When a charged particle is bent in a magnetic field, it emits photons. The process depends greatly on the mass of the accelerated particle; electrons produce much more synchrotron radiation at a given energy

than protons or heavier particles. Some machines, called *light sources*, accelerate electrons and positrons specifically for the purpose of producing synchrotron radiation.

5. Neutrons

EO-16 DISCUSS special instruments and measurement techniques.

Neutrons can be produced through nuclear interactions of the primary or secondary beam with matter. They can also be produced by interaction of high-energy photons with matter (photonuetron reaction). The photoneutron reaction typically requires photons with energy in excess of 10 MeV. Neutron radiation is a concern within any area where the beam can interact with matter, such as targets, beamline components, etc.

Neutrons do not lose energy by direct ionization like charged particles. They gradually lose their energy through collisions with atoms in material. The most effective shielding is material that contains hydrogen, such as concrete, earth, or water. When a neutron collides with a hydrogen nucleus containing one proton, the neutron transfers energy to the proton (like two billiard balls colliding). The proton is easily stopped because it is a charged particle.

Labyrinth designs are often used to "trap" neutrons as they ricochet.

Location of potential sources of neutron radiation exposure. (Facility Specific)

6. Muons

Muons are short-lived particles that are physically similar to electrons, but about 200 times heavier.

Muons are produced by several mechanisms and require photon energies greater than 212 MeV or proton energies greater than 140 MeV. Muons are not usually seen in significant amounts at machines with energies less than 1 giga volt (GeV = $1x10^9$ eV).

Muons travel mainly in the direction of the beam that produced them with very little deviation from the beam path. They are a concern directly downstream of targets, beam dumps, etc. Muons are ionizing particles and can deliver a very high dose.

Muons lose energy only through ionization and are very penetrating. Large amounts of earth and steel are typically used to shield muons. Muons travel mainly in the forward direction of the beam. They are a concern directly downstream of thick targets, beam dumps, apertures, etc.

7. (Facility Specific) Identify Prompt Radiation Sources

EO-06 IDENTIFY prompt radiation sources at site.

B. Residual Radioactivation

EO-07 DEFINE radioactivation.

EO-10 IDENTIFY activation products.

The process by which materials become radioactive is commonly referred to as "radioactivation" or simply "activation." Material, air, water, and components that are subject to high-energy prompt radiations (typically with threshold energies above 10 MeV for particles other than neutrons) may be made radioactive.

1. Residual radioactivity

Activated materials emit radiation from radioactive decay after shut-off of the beam.

2. Contaminated material versus activated material

   It is important to understand the difference between "activated material" and "contaminated material." Contaminated materials are items with removable or fixed surface contamination. Activated material is radioactive material dispersed throughout the item.

   Activated materials normally do not present a potential loose contamination hazard except during activities such as:

   - Grinding.
   - Burning.
   - Machining.
   - Handling coolant water filters.

   Target spallation may also create contamination without any physical operation applied.

   Activated materials are normally controlled based on the external radiation dose rate.

3. Activated materials

EO-08 IDENTIFY activation sources at facility.

All materials located within an accelerator enclosure have the potential to be radioactivated if subjected to primary or secondary beams.

This may include shielding and structural materials and

- Any material within the accelerator enclosure.
- Beamline components.
- Air.
- Cooling liquids and working fluids.

4. Beamline components

Beamline components may become activated (radioactive) depending on:

- Nature of the material.
- Proximity to the beam.
- Beam characteristics.

Items that intercept a portion of the beam are most likely to be activated and contaminated. Among those items that have the highest probability for activation are:

- Targets: Targets are devices designed to intercept a portion of the beam for the purposes of producing secondary beams of particles or physical reactions.
- Beam dumps or stops: Beam dumps or stops are used to absorb the beam at the end of a beam cycle.
- Collimators and scrapers: Collimators and scrapers are used to remove particles (halo) that have drifted from the highly collimated beam.
- Septa and other magnets: Septa and other magnets are used to align and direct beams.
- Cavities and beamline: Beamline piping and items such as resonating cavities, diagnostic devices, etc., may become activated.

5. Air

Air, dust, and other gases in the accelerator enclosure may be activated. Typically, the activation products are short-lived gaseous radionuclides of the elements in the air or particulate, in the case of dust particles. One example is Oxygen-15 which is produced from Nitrogen-14 and Oxygen-16.

6. Liquids

Liquids subject to activation include:

- Cooling water: Cooling water is used for cooling beamline components (activation products such as tritium, H-3, and wear products from piping).
- Oil in vacuum pumps of beam line components.
- Cryogenic fluids: Liquid helium and nitrogen are used frequently to cool components.

7. Facility Specific (Insert facility-specific information concerning radioactivation.)

8. Contamination

Materials and activities that could create contamination concerns include:

- Surface coating: Surface coating, such as paint or oxidation and/or rust, may present a contamination problem. Such coatings may be easily removable and may be present in areas not commonly accessed, such as beam dump vaults.
- Compounds: Compounds, such as grease, sealants, gaskets, and anti-seize coatings, may be activated depending on their composition. During maintenance, these compounds should be chosen carefully to minimize the production of contamination if possible. These materials may not be accessible until after components are disassembled; therefore, the need for carefully planned maintenance activities involving such compounds should be highlighted.
- Impurities: Impurities in cooling water systems can be a source of contamination. This source may be found in a filter/resin media system.

- Activities: (Facility Specific) Routine work areas and tasks where contamination control must be considered:

- Machining of radioactive materials.

- Cooling water filters.

- Accessing beamline.

- Maintenance.

- Target removal.

- Etc.

C. Ancillary Sources

EO-09 IDENTIFY ancillary sources at site (Facility Specific)

Accelerators employ devices to impart energy to particles or redirect them during the acceleration process. These devices may emit ionizing radiation while they are operating.

1. Klystrons

   Klystrons provide power to accelerate charged particles. They emit X-rays during operation.

2. Radiofrequency cavities

   These devices accelerate charged particles using electromagnetic fields. Electrical discharges within the RF cavity cause photon emission.

3. Electrostatic separators/Septa

   These devices split a particle beam into two beams using static electric fields. The high voltages associated with these devices cause electrons to accelerate in the vacuum within the beamline. They emit X-rays. Septa are also a high source of activation and residual radiation.

4. Facility Specific (Insert facility specific information concerning ancillary sources of radiation)

IV. TYPES OF CONTROLS

EO-12 DESCRIBE each access mode at the facility and access to beam and beam containment including interlocks and warning devices and systems.*

Many types of controls are used at accelerator facilities to protect personnel from exposure to ionizing radiation and other hazards such as:

- Electrical.
- Mechanical.
- Cryogenic.
- Non-ionizing radiation.

The design of an effective safety program incorporates a combination of engineered and administrative controls and personnel protective equipment, (e.g., respirators, protective clothing etc). However, per 10 CFR 835.1001(a) the primary methods used shall be physical design features. Administrative controls and procedural requirements shall be employed only as supplemental methods to control radiation exposure.

The following sections describe the various controls encountered at accelerator facilities that are designed to protect personnel from ionizing radiation.

EO-11 IDENTIFY engineered and administration controls (Facility Specific)

A. Engineered Controls

Equipment designed to protect personnel from a hazard by preventing entry to accelerator enclosures, providing a warning of impending beam, or means to shield out or remove the source of the hazard. Engineered controls may be active or passive.

1. Passive engineered controls

   Once installed, passive engineered controls require no further action to perform their intended function. Passive engineered controls may include:

   - Radiation shielding such as concrete blocks, iron plates, lead bricks and earth berms; and

   - Barriers such as fences, locked gates, and doors.

2. Active engineered controls

   Active engineered controls include devices that sense changing conditions and can trigger a safety action. Personnel are prevented from accessing beamline areas when the accelerator is operated. All access points are protected by doors or gates that are both locked and interlocked. The interlock sensors will turn off the beam in the event a door is opened.

   - Safety interlock devices include:

     - Area radiation monitors.

     - Access gate sensors.

     - "Crash" or "scram" buttons.

B. Administrative Controls

Administrative controls include programs and procedures that personnel must implement to provide protection from hazards.

1. Search and secure (sweep) procedures

   Search and secure (sweep) procedures are used to verify that no personnel remain in a beamline enclosure when it is being prepared to receive beam.

2. Controlled access procedures (including key control)

   Controlled access procedures allow personnel to access a beamline enclosure while it remains interlocked. There is no physical search of the area before the beam is restored.

3. Radiological Work Permits (RWPs)

   RWPs provide written documentation of job descriptions, radiological conditions, and the required protective controls .

4. Configuration control procedures

   Configuration control procedures ensure that important information about the configuration of a facility is accurate and that the configuration retains it functional purpose.

5. Radiological monitoring programs

   Radiological monitoring programs provide assurance that the accelerator facility operates within the radiological safety design specifications and ALARA goals.

6. Warning indicators

   - Status lights, and
   - Alarms.

C. Accelerator Facility Access Modes (Facility Specific)

EO-12 DESCRIBE each access mode at the site.

Accelerators have several possible states or modes regarding accessibility. Each facility may use different terminology but the following modes are nearly universal.

1. Normal or open access mode

   Beam area is not interlocked and beam cannot operate. Access to these areas is unrestricted after a radiation survey to identify and isolate areas of activation of contamination.

2. Search & secure mode

   Operators physically search beam area to ensure no personnel are present and to lock access gates. Personnel must immediately leave area by the path designated by the search party.

3. Controlled access mode

   Beam area has been searched and secured and remains interlocked; however, beam cannot operate. Limited personnel access is allowed. There is no search of area following the access.

4. Test mode

   Certain devices, (e.g. magnets) may be energized to allow testing. Beam production components with equipment are locked out so beam cannot operate. Limited personnel may access but must be aware of hazardous conditions, (e.g., electrical power).

5. Exclusion mode

Beam may be present. Access is prohibited.

D. Configuration Control Program

The facility design must continue to meet its intended function while providing for adequate personnel safety. Configuration control ensures that only authorized changes are made and that any changes made continue to provide adequate personnel safety.

1. Elements of a program

Configuration control programs for accelerator facilities include:

- Inventory and labeling of controlled devices.
- Periodic inspections.
- Procedures and authorizations for change and/or restoration of configuration.
- Testing to verify proper configuration.

2. Structures and equipment

These must be maintained in a specific configuration to perform the desired safety function. Examples include:

- Radiation shielding.
- Magnets.
- Stops.
- Detectors.

- Interlocks and access system wiring.

3. Facility Specific (Insert facility-specific configuration control procedures.)

EO-13 DISCUSS Site Configuration control program (Facility Specific).

V. MONITORING

EO-15 STATE purpose of initial entry survey.

Monitoring refers to the checking, testing, and surveying of individuals, work areas, materials/equipment, and environment for ionizing radiation and radioactivity.

A. Qualification of Monitors

Monitoring for radiation at accelerators can be complicated. Special techniques and instrumentation may be necessary due to the existence of:

- Mixed radiation fields.
- Pulsed beams.
- Very high energy particles.
- High intensities of radiation (dose rates).
- Magnetic and RF fields.

Monitoring is only performed by Radiological Control Personnel or others who are specifically trained and qualified to perform monitoring.

The following are some requirements and recommendations regarding monitoring and personnel performing monitoring:

- Personnel shall be trained and qualified to use instruments.

- Instruments shall be calibrated.

- Instruments shall be source checked daily or prior to use.

- Only Radiological Control Technicians (RCTs) may conduct monitoring for establishing or disestablishing radiological controls.

B. Area Monitoring

Area monitoring at accelerator facilities refers to using fixed and/or portable instruments and contamination swipes to detect and measure:

- Prompt radiation.

- Residual radiation.

C. Prompt Radiation Monitoring

Prompt radiation monitoring is to ensure radiation levels are within design parameters.

1. Instrumentation

   Prompt radiation surveys may utilize fixed and/or portable instruments.
   Discuss facility-specific instruments.

2. Pulsed radiation

   Prompt pulsed radiations must be measured with specialized survey instruments.
   Discuss facility-specific instruments.

3. Neutron radiation

Neutron monitoring is complicated because the quality factor depends on the energy of the neutron. As for all surveys, neutron surveys must be conducted by qualified individuals.

D. Residual Radiation

Radioactive materials may be found in the form of:

- Removable contamination.
- Fixed contamination.
- Activated materials.
- Volume contamination.

1. Residual radiation monitoring

These radioactive materials may present an external radiation (dose rate) or contamination hazard. Residual radiation is typically monitored with portable instruments and contamination swipes. Types of monitoring may include:

- Work areas and shops.
- Items/materials.
- Operational systems.

2. Monitoring instruments

   Special instruments may be needed for monitoring residual activity in materials depending on:

   - Nature of material.
   - Physical form (e.g., liquids).

3. Work areas

   Types of work area surveys include:

   - Radiation (dose rate) surveys.
   - Loose surface contamination surveys.
   - Air sampling, including continuous air monitoring.

4. Items/materials monitoring

EO-17 STATE site requirements for removing material from beam enclosure.

The purpose of monitoring materials is to ensure radioactive materials are identified and controlled within radiologically controlled areas. All items/materials must be surveyed prior to removal from areas of potential activation/contamination.

Typically this includes any material inside the beam enclosures, targets and shielded structures.

5. Cooling water and other systems

   Typical monitoring may include:

   - Sampling component water (on and off site).
   - Monitoring filter media.

E. Environmental Monitoring

Environmental sampling/monitoring includes monitoring for prompt and residual radiation and may include:

- Prompt radiation levels (skyshine, muons, etc.).
- Radiation levels at site boundary from storage areas, etc.
- Sampling of exhaust air (air activation products).
- Surface/ground water (on and offsite).
- Monitoring of radiation levels at site boundary.
- Soil/vegetation/deposition near liquid discharges and air exhaust.

F. Personnel Monitoring

1. Personnel dosimetry (insert facility-specific information)

2. Personnel contamination monitoring at electron and proton accelerator facilities

   Electron facilities typically will have a lower incidence of contamination than proton facilities due to the higher neutron flux produced by proton collisions.

3. Locations (insert facility-specific information)

4. Jobs/tasks (insert facility-specific information)

   Job/tasks that have a potential for contamination include and may require personnel contamination monitoring include:

   - Machining and welding of activated materials.
   - Handling water used to cool accelerator components.
   - Handling sealed sources suspected of leakage.
   - Entering target rooms.
   - Accidental releases.

VI. RADIOACTIVE WASTE ISSUES

A. Sources of Radioactive Waste

The radioactive waste from an accelerator facility tends to be mostly machine components or experimental equipment used in or near the particle beam. These components are often of copper, iron (steel), and aluminum. Other items or tasks contributing to radioactive waste are:

- Shielding blocks (iron, lead, or concrete).
- Coolant.
- Maintenance/modifications.
- Cleaning materials.

1. Shielding blocks (iron, lead, or concrete)

Shielding blocks are quite large and their highest activity is usually below the surface. Shielding blocks showing several rad/hr at the surface may have no removable (wipeable) surface contamination and can be stored without contamination problems. Whenever possible, shielding blocks should be stored for reuse where dose is not a problem.

2. Coolants

If possible, cooling water should be cleaned and recirculated/ reused. The use of “pure” water minimizes the radioactivation problems caused by impurities.

It may be desirable to dispose of water before the tritium concentration becomes too high. Cooling system capacities range from less than 10 gallons to tens of thousands of gallons. Some possibilities for disposal are:

- Sanitary sewer: Disposal through the sanitary sewer. This may be regulated by several agencies, such as DOE, NRC, EPA, and State and local water pollution control boards. Their regulations will set concentration limits and, perhaps, annual limits.

- Evaporation: The water can be evaporated in engineered evaporation systems.

- Solidification: The water can be used to make concrete for solidifying other liquid wastes for disposal.

- Decay: Water from a small-volume, high concentration system could be transferred to a large-volume low concentration system where it can decay safely.

- Ion exchange resins and filters: These are used to remove impurities from recirculating cooling water systems and can accumulate radionuclides such as Be-7, Na-22, Mn-54, and Co-60.

3. Maintenance/modifications

Radioactive waste can be generated by maintenance and modification of beamline components. Waste from this source may consist of:

- Compactables: Compactables such as rags, anti-contamination clothing, surface coverings, etc.

- Tools, equipment, components: Items that are no longer of use. These may consist of materials contaminated by the transfer of activated radioactive material to their surface or items that are radioactivated from being in the beamline.

4. Soils

Soils surrounding buried beam dumps may become activated. These can become classified as radioactive waste when facilities are modified or decommissioned.

B. Minimizing Radioactive Waste

EO-18 IDENTIFY methods to minimize radioactive waste at the facility.

Because of the difficulty and cost in disposing of radioactive waste, special care should be taken to minimize waste generated.

Methods for reducing radioactive waste generation:

- Avoid bringing unnecessary material into areas where contamination may be present or where they may become activated.
- Designate an area to store contaminated tools for reuse.
- Plan your work so that, whenever possible, construction and clean maintenance can be done in a clean area.
- Do not leave unnecessary tools and equipment in accelerator enclosures.
- Reuse items.

C. Mixed Waste

Mixed waste is waste that is classified as hazardous in accordance with the Environmental Protection Agency (EPA) and is also radioactive. There is presently no approved method to dispose of mixed waste, and long-term storage is required. Common examples of waste materials at accelerators are:

- Lead (shielding, batteries, etc.).
- PCBs.

- Cadmium.

- Acids.

- Bases.

- Solvents and degreasers.

D. Minimizing Mixed Waste

- Use non-hazardous cleaning materials for decontamination whenever possible.

- Segregate "radioactive only" from "hazardous only" at the source and

- Explore the use of non-hazardous materials in radiological areas to prevent the generation of mixed waste.

VII. ABNORMAL CONDITIONS

EO-19 IDENTIFY facility alarms and responses to abnormal conditions.

To properly deal with unexpected abnormal situations occurring in an accelerator facility, a well-thought-out response program and personnel trained to execute the responses should be in place. Abnormal conditions may include:

A. Loss of Beam Containment (insert facility-specific information).

B. Radiation Overexposure (insert facility-specific information).

C. Fires (insert facility-specific information).

D. Loss of Radioactive Material (insert facility-specific information).

E. Facility Alarms (insert facility-specific information)

F. Safety Assessment Document (SAD).

DOE Order 5480.25 requires a SAD for accelerators. The SAD provides analysis of the potential accidents that can be experienced at a particular facility and outlines the accelerator's safety envelope.

VIII. LESSONS LEARNED (insert facility-specific Lessons Learned).

IX. SUMMARY AND REVIEW (Insert general summary and review including facility-specific information.)

BIBLIOGRAPHY: **DOE standards, handbooks, and technical standards lists (TSLs).** **The following DOE standards, handbooks, and TSLs form a part of this document to the extent specified herein.**

U.S. Department of Energy, *Guidelines for Evaluation of Nuclear Facility Training Programs*, DOE - STD 1070-94.

U.S. Department of Energy, *Guide to Good Practices for Training and Qualification of Instructors*, DOE-NE-STD-1001-91, Washington, D.C. (1991).

U.S. Department of Energy, *Radiological Control Manual*, DOE/EH-0256T, Washington, D.C. (1994).

U.S. Department of Energy, McCall, R.C. et. al, *Health Physics Manual of Good Practices for Accelerator Facilities*, SLAC-327, Stanford Linear Accelerator Center, Stanford, CA, April 1988.

U.S. Department of Energy, *Safety of Accelerator Facilities*, DOE Order 5480.25.

U.S. Department of Energy, *Personnel Selection, Qualification, Training and Staffing Requirements at DOE Reactors and Non-Reactor Nuclear Facilities*, DOE Order 5480.20A.

Other government documents, drawings, and publications. The following government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise indicated, the issues of these documents are those cited in the contracting document.

Title 10, Code of Federal Regulations, Part 835, "Occupational Radiation Protection."

Non-Government documents

Cooper, L., *An Introduction to the Meaning and Structure of Physics*, Harper & Row, Publishers, NY, 1968.

BIBLIOGRAPHY (continued)

Kernan, W. J., Accelerators, U.S. Atomic Energy Commission, Division of Technical Information, *Understanding the Atom Series*.

Metropolis, K., editor, *The Superconducting Super Collider, An Introduction to Radiation Protection for the Superconducting Super Collider*, Task Force Report SSC-SR-1027, November 10, 1987.

Patterson, W. H., Thomas R. H., editors, *A History of Accelerator Radiation Protection, Personal and Professional Memoirs*, Nuclear Technology Publishing, Kent, England, 1994.

Toohig, T.E., editor, Workshop on Radiological Aspects of SSC Operations, SSC-SR-1031, May 1987.

Universities Research Association, *To the Heart of Matter - The Superconducting Super Collider*, Universities Research Association, Washington D.C., January 1987.

GLOSSARY

Accelerator: A device employing electrostatic or electromagnetic fields to input kinetic energy to molecules, atomic, or subatomic particles, and capable of creating a radiological area.

Access control system: Engineered or administrative systems that manage radiation dose to personnel by limiting personnel entry.

Actinide Transmutation: Transformation of actinides through neutron activation.

Activity: The rate at which a source emits radiation is called its activity. Activity is measured in terms of the number of disintegrations that take place every second. The unit for activity used at DOE sites is the curie (Ci). One curie is equal to 37 billion (3.7×10^{10}) disintegrations per second.

Annual Limit on Intake (ALI): Means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. (see 10CFR 835)

Attenuation: The process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux intensity.

Beam: A flow of electromagnetic or particulate radiation that is either collimated and generally unidirectional, or divergent from a small source but restricted to a small solid angle.

Beam scrapers: Beam scrapers remove particles that have wandered from the central area of the beam.

Bremsstrahlung: Secondary photon radiation produced by deceleration of charged particles passing through matter.

Collider: An accelerator in which two opposed beams of particles collide head-on.

Continuous Air Monitor (CAM): Instrument that continuously samples and measures the levels of *airborne radioactive materials* on a "real time" basis and has alarm capabilities at preset levels.

GLOSSARY (continued)

Cryostat: An instrument or device that maintains low temperature for superconducting magnets.

Cyclotron: A cyclic accelerator in which the charged particles spiral outward from the center of the machine as they gain energy.

Decommissioning: The process of closing and securing a nuclear facility, or nuclear materials storage facility, so as to provide adequate protection from radiation exposure and to isolate radioactive contamination from the human environment.

Depleted Uranium: Uranium having a percentage of uranium-235 smaller than the 0.7% found in natural uranium.

Derived Air Concentration (DAC): The airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2,000 hours (assuming a breathing volume of 2,400 m^3).

Detector: Any device that can detect the presence of an energetic electromagnetic radiation particle or nuclear fragment and measure one or more of its properties.

Electromagnetic Radiation: A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from *X-rays* and *gamma rays* of short wavelength, through the ultraviolet, visible and infrared regions, radar and radio waves of relatively long wavelength.

Enclosed Beam: All possible X-ray beam paths are fully contained in protective enclosures so that no part of the body can intercept the beam during normal operation.

Electron volt: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt.

Exclusion Area: Any area to which access is prohibited for the purpose of protection of individuals.

GLOSSARY (continued)

Fail-Safe: A design feature built into a system or system component so that the most likely mode of failure causes the production of X-rays to be turned off. If fail-safe design is not possible or cost-effective, the system or system component should be designed so that no single failure will cause unsafe operation.

Interlock: A safety device that automatically renders an area safe from prompt radiation when the device is actuated.

Linear accelerator: A device that accelerates charged particles along a straight line.

Mixed Waste: Waste containing both radioactive and hazardous components as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.

Muon: An elementary particle apparently identical to the electron except for being 200 times heavier.

Neutron: Elementary particle with a mass approximately the same as that of a hydrogen *atom* and electrically neutral.

Nucleus: The small, central, positively charged region of an *atom* that carries essentially all the mass.

Pion: A cosmic particle with a mass about 273 times that of an *electron* and a half-life of 2/100,000,000 (2×10^{-8}) of a second. Positive, negative, and neutral pions exist.

Primary Beam: *Radiation* that passes through the window, aperture, cone, or other collimating device of the source housing. Sometimes called *useful beam*.

Prompt radiation: Radiation resulting from the accelerator beam or the interaction of the accelerator beam with surrounding matter that ceases shortly after the beam is removed. Activation products and area contamination are not considered prompt radiation.

Proton: An elementary nuclear particle with a positive electric charge and an atomic weight of approximately one.

GLOSSARY (continued)

Radiation: Radiation refers to the emission and propagation of waves or particles through matter or space. Matter absorbs energy from radiation. In a microwave oven, for example, food absorbs energy from microwave radiation and is heated and cooked.

Radiation alarm system: A system providing notification, including activation of a radiation warning system, that a radiation condition exists that exceeds preset limits. An alarm system may initiate mitigating action.

Radiation warning light: A system that alerts personnel to a potential or actual change in the radiation level in a working environment. A warning system does not initiate mitigating actions.

Radioactivation or Activation: The process of producing a radioactive material by bombardment with neutrons, protons, or other nuclear particles.

Redundancy: Duplication or repetition of elements in electronic or mechanical equipment to provide alternative functional channels in case of failure.

Scattered Radiation: *Radiation* that, during passage through matter, has been deviated in direction. It may have been modified also by a decrease in energy.

Scram switch: An interlock that is intended for emergency use only. Scram switches are usually placed within exclusion areas where personnel may be caught during pre-start-up or actual operations.

Search: (This is commonly referred to as a sweep.) A physical inspection carried out under controlled conditions to ensure that no personnel are left inside exclusion areas.

Septa: An area associated with an accelerator beam line where the beam is split into two or more beams, normally through the use of magnets. This area is prone to radioactivation due to the interaction of the beam with structural materials.

GLOSSARY (continued)

Spectra: A visual display, a photographical record, or a plot of the distribution of the intensity of radiation at a given kind as a function of its wavelength, energy, frequency, momentum, mass, or any related quantity.

Spallation: A term used to denote a nuclear reaction induced by high-energy bombardment and involves the ejection of two or more particles.

Superconductivity: The ability of some materials to carry an electric current with no power loss, owing to the complete absence of electrical resistance. To date, superconductivity has been found only in a few metals and alloys and at very low temperatures.

Synchrotron: An accelerator in which the energy of charged particles is increased as they travel around a circular orbit of fixed radius.

Useful Beam: *Radiation* that passes through the window, aperture, cone, or other collimating device of the source housing. Sometimes called *primary beam*.

Volt: The term potential difference symbolized by V is defined as the work per unit charge done in moving a charge from one point to the other.

CONCLUDING MATERIAL

Review Activity:			**Preparing Activity:**
DOE	Operations Offices	Field Offices	DOE-EH-52
DP	AL	RFFO	
EH	CH	OH	**Project Number:**
EM	ID	GFO	6910-0055
NE	NV		
NN	OR		
ER	RL		
	OAK		
	SR		

National Laboratories	Area Offices
BNL	Amarillo Area Office
LLNL	Ashtabula Area Office
LANL	Carlsbad Area Office
PNNL	Columbus Area Office
Sandia	Fernald Area Office
FNL	Los Alamos Area Office
	West Valley Area Office
	Kirtland Area Office
	Pinellas Area Office
	Kansas City Area Office
	Miamisburg Area Office